FOREWORD

When a movement makes such rapid advances as Statistical Quality Control it rapidly becomes departmentalized into kindred industries, and previously reported work and applications become buried in a mass of information pertaining to the subject as a whole. This first Technical Supplement by the American Society for Quality Control is an effort to classify such information so that workers in a particular field can more easily find those things of direct interest to them.

Because of this need for classifications, the American Society for Quality Control is developing a series of Technical Supplements to *Industrial Quality Control* , each sponsored by the Technical Division or Committee responsible.

The newly formed Textile Division has the honor to be the first to develop a Technical Supplement. It represents much effort by many members of the Textile Technical Committee under the leadership of W. S. Smith, Chairman. Prof. D. S. Hamby, as editor, made the final compilations, assisted by Cleveland Adams, John H. Reynolds, Allen R. Crawford and T. R. Bainbridge as group leaders, with many others contributing as members of the "team." To them acknowledgement should be made for their fine effort and cooperation.

How often and how extensively these supplements will be prepared depends on the members of the Society and how much they desire and use them. Your comments are urgently requested.

Julian H. Toulouse, Vice President
Coordinator of Activities of the
Technical Committees and Divisions.

Simon Collier, President

STATEMENT OF EDITORIAL POLICY

Papers published in this and succeeding technical supplements to Industrial Quality Control represent the joint and sole effort of the Editorial Committee of the particular Technical Division concerned and the respective contributors. The Editorial Board for *Industrial Quality Control* takes no active part in reviewing, editing, or approving the manuscripts published in these supplements, and hence assumes no responsibility for them.

Mason E. Wescott
Chairman of the Editorial Board
American Society for Quality Control

THE FORMATION OF A TEXTILE DIVISION

The American Society for Quality Control has grown very rapidly since its organization and it now includes in its membership representatives from practically all types of industries. To handle minor affairs directly related to the various industries and to unify the interests of members in each industry, the Society under the administration of President Weaver appointed six technical committees. The Textile Committee was one of these original six and was appointed late in 1950.

The Textile Committee sponsored a textile conference in August, 1951, at Clemson, South Carolina. Attendance and interest exhibited at this meeting initiated subcommittees and task groups through which individual members became active in committee affairs. As a result of the tremendous interest and large attendance, the original idea of a committee's functions was quickly outgrown, and division status was recommended.

Mr. Weaver and his special assistant, Dr. Julian H. Toulouse, investigated these recommendations and were favorable to further efforts along these lines, and appointed a Chairman of a Steering Committee to work toward this objective. The Steering Committee, with the help of Dr. Toulouse and approval of Mr. Weaver, prepared an organization plan that met the approval of the Executive Committee and Board of Directors of the Society. Permission was granted to proceed with the election of officers and complete the work of the Steering Committee. It is expected that by the time of the next Clemson meeting, an election of Division officers will have been held by mail, and that at the meeting the President of the Society will present the Chairman of the Division with a Charter and set of By-laws. Thus, at the Fall meeting to be held at Clemson, South Carolina, these final steps will have been taken. The Textile Committee will be dissolved, and a Textile Division will take over its functions and assume additional duties.

The aim of the Textile Division will be to procreate interest in quality control in the particular field of the textile industry. It will accomplish this by holding meetings, stimulating publication of articles on textile applications, and aid its members in every other way possible and appropriate to become more proficient as quality control engineers. The only requirement for membership in the Division will be membership in A.S.Q.C. and a desire for affiliation with the Division. The Division will elect its own officers, and its governing body will be a council composed of these officers, regional councilmen from regions with a sufficiently large divisional membership, and one society vice-president. The Divi-

sion will be authorized to hold its own meetings at times and places of its own choosing, just so long as these do not interfere with sectional or national meetings.

W. S. Smith, Chairman
Textile Technical Committee

John H. Reynolds, Chairman
Steering Committee for Formation of Textile Division

TEXTILE DIVISION SUPPLEMENT

This Supplement to the journal, *Industrial Quality Control*, the official publication of the American Society for Quality Control, is the first supplement to be sponsored by the national organization of A.S.Q.C.

The textile members of A.S.Q.C. feel honored at being the first group to reach divisional status and to have the first technical supplement devoted to the textile industry. The purpose of this Textile Supplement is manyfold. It is hoped by the editors that the material included will be beneficial to quality control engineers and any other persons interested in quality control. It is also hoped that it will serve to acquaint the members of the textile industry with the type of work planned by the Textile Division for its members.

The Technical Editor wishes to acknowledge the splendid cooperation received from the authors in preparing and submitting the manuscripts and also to thank the officers of A.S.Q.C. for their helpful suggestions and guidance.

D. S. Hamby
Technical Editor

SOCIETY OFFICERS

Simon Collier, President
Johns-Manville Corporation
New York, N.Y.

Julian H. Toulouse, Vice President
Owens-Illinois Glass Co.
Toledo, Ohio

Arthur Bender Jr., Vice President
Delco-Remy – Division G.M.C.
Anderson, Indiana

Edward B. Haden, Executive Secretary
The Esterbrook Pen Co.
Camden, N. J.

Raymond S. Saddoris, Vice President
O. A. Smith Corporation
Milwaukee, Wisconsin

Paul A. Robert, Treasurer
International Business Machines Corp.
Endicott, N. Y.

CONTENTS

Statistics in the Textile Industry – E. R. Schwartz 1

Quality Control in the Textile Industry – Gardner H. Hailes 5

Tolerances for Cotton Strength Testing 11
M. Earl Heard and W. S. Smith

Quality Control in Cotton Mixing – J. B. Denmark 16

Can Good Sliver Be Improved – W. V. Hassett 21

Control of Stock Size at Draw Frame 26
M. Earl Heard and C. G. Bramlett

Wamsutta's Quality Control Program – Edward S. Rudnick 29

Quality Control in a Weave Room – Mary Jo Wesson 34

Application of Statistical Methods to Weaving and Inspection 41
H. A. Le Duc

Two Textile Applications of the Chi-Square Control Chart 49
J. H. Reynolds

Statistical Sampling and Testing of Lots of Raw Wool 55
Robert C. Levitch and Robert R. Jones

Quality Control in the Manufacture of Cellulose Acetate Yarn 61
F. J. Fitzgerald

Analysis of Variance Applied to Textile Processes 67
Edward S. Rudnick

Statistical Quality Control in the Textile Mill – N. L. Enrick 78

Bibliography on Statistical Quality Control as Related to the Textile Industry – Bibliography Committee 83

Copyright 1952
American Society for Quality Control
Room 5036 – 70 East 45th.Street
New York 17, N.Y.

Printed by
Multicopy Corporation
518 Kedzie Street
Evanston, Illinois

STATISTICS IN THE TEXTILE INDUSTRY

E. R. Schwarz, F. T I. *

Over the last twenty years more and more attention has been paid by research workers in textile technology and by textile manufacturers to the use of statistical methods. In the former instance experiments have been more intelligently planned and executed and the resulting data has been more effectively handled and interpreted. In the latter instance emphasis has been placed on methods of quality control.

Unlike many industries, textile manufacturing is concerned much more with the control of variables than with attributes. Thus the measurement of properties as they affect the product takes precedence over inspection techniques. This involves use of such statistical tools as significance testing*, correlation analyses, rank correlations, planned sampling, and increasingly, variance analysis.

Following some of the early work at the M. I. T. Textile Division in the field of fundamental textile research, L. H. C. Tippett of Shirley Institute, Manchester, England was invited to join a group of some ten or a dozen leaders in the field of industrial statistics for a special conference at M. I. T. in September of 1938. A substantial number of the ninety-four concerns represented were in textiles and the Proceedings of the Industrial Statistics Conference were later published by the Pitman Publishing Corporation. Among other subjects the coverage of the conference included:

THE STATISTICAL PRINCIPLES OF EXPERIMENTATION WITH PARTICULAR REFERENCE TO EXPERIMENTATION IN TEXTILE FACTORIES.

WHY THE KENDALL COMPANY IS INTERESTED IN STATISTICAL METHODS.

STATISTICAL ASPECTS OF QUALITY CONTROL IN TEXTILE MANUFACTURE.

In succeeding years progress was continuous and in 1948 Mr. Tippett again was invited to deliver a series of lectures on Industrial Statistics at M. I. T. to which representatives of a number of industries including textiles were invited. The result was publication by Tippett in 1950 of the volume entitled "Technological Applications of Statistics" as a part of the Wiley Publications in Statistics series. Many of the illustrations and cases discussed in this book were from the textile industry.

* *Professor of Textile Technology and Head of the Textile Division at the Massachusetts Institute of Technology. Honorary Member – Boston Section A.S.Q.C.*

In the meantime, also, there was steadily increasing use of statistics in textile research and statistical analyses of all sorts appeared in technical papers published in Textile World, Textile Industries, Textile Research Journal and the Journal of the Textile Institute.

Typical examples are to be found in the work of Ashcroft[2] who discusses quality control charts as an aid to textile manufacturers in meeting the requirements of the armed forces, and of Beckwith[4] who points out six advantages of the control chart method of controlling quality in textile manufacturing. Just plotting data gives men a quick grasp of past, present and expected future quality levels beyond that obtained by merely tabulating data. Further it provides definite assurance to the responsible individuals that some change in quality has taken place when the control limits are exceeded. Records are also provided to safeguard against possible inadequate later testing by the consumer. It enables the manufacturer to locate causes of trouble sooner than by a non-systematic test method. Under control, variation in product quality is that resulting from chance causes only and average levels of quality can be brought down near to minimum of specifications with substantial savings as a result. It is also possible to reduce the amount of testing and to cut inspection costs.

The American Society for Quality Control sponsored through several of its chapters educational group meetings and conferences in such educational institutions as the Textile School of North Carolina State College, Lowell Textile Institute, M. I. T. and elsewhere. Initially, the emphasis was on the control chart and its use, but recently the emphasis has shifted to the matter of quality itself. Much attention is being given to determining what quality should be controlled, and in particular, what tests or techniques should be used to measure it. Some of the early work was not as fruitful as it might have been because in certain instances the measurements made were not true measures of the quality being studied. In many such cases procedures were dictated by the type of equipment available in the laboratory or by habits formed over the years.

Then too, some of the earlier work was made difficult because of inadequate instrumentation. The advent of servo mechanisms and of such devices as the bonded electric wire resistance strain gage, the oscilloscope, sonic and supersonic sound wave velocity techniques, the Uster Evenness Tester, the Saco-Lowell Evenness tester, the photoelectric Fibrograph, the drapeometer and the like made possible the measurement of qualities not possible of evaluation before. Increasing attention was paid to relating the consumer performance requirements to the properties and structure of the textile material. Rank correlation [1 3] was of inestimable value here and currently variance analysis is playing a very

important role [5 13].

In research for example, the conventional laboratory procedure when three factors – let us say A, B, and C –were being studied in order to relate their behavior in service with laboratory findings, was to hold two of the three factors constant while the third was being measured. It was thus possible to obtain values for A, B, and C but only occasionally were these realistically related to service. This is understandable since in service all three factors varied and might even be interelated. Properly planned sampling makes possible variance analyses in which the magnitude, nature and significance of the variations produced by the normal action of the three factors may be determined. Instead of being preoccupied with the magnitudes of the factors involved, the research worker now devotes much of his attention to the sources and amounts of variation produced [14]. Such work as a part of quality control studies is extremely important.

The textile industry is daily becoming more aware of the importance of uniformity of product and much of its machine and product research is centered about this phase of manufacture. The result is evident in the super and control draft installations in roving and spinning equipment; the advent of the Warner–Swasey pin drafter and improved opening, picking and combing machinery. It is particularly interesting to note that the improvement in quality of yarn and fabric has moved the pressure for better control of quality [10] back through preceding operations [7] to the very start of the process and even to the raw material itself [11 12 15]. Of course the greater uniformity in certain respects which is typical of the synthetic fibers has resulted in intensive studies of the means by which natural fibers may be improved in uniformity or lacking this, be better graded, sorted and re-combined.

In the study of properties certain are relatively simple and involve measurement of length, width, thickness, area, volume, density, twist, spacing, and weight. More complex determinations are load–deformation relationships, energy absorption characteristics, deformation, –time–temperature changes, primary creep, secondary creep, immediate elastic deformations, bending moduli, instantaneous elastic moduli, compressional resilience, impact behaviour, abrasion resistance, air permeability, water repellance, drape, flexibility, repeated stress, heat transmission. Whether simple or complex there are variations involved, distribution to be analyzed[3], trends to be studied, interactions to be investigated, precision and quality limits to be established. All these require statistical techniques in use. There is more, however, than simply a knowledge of how to use the charts and formulas or how to set them up. The individual concerned must realize and understand the background upon which the

theories are based. The fundamental concepts of population, distribution, dispersion, standard deviation, variance and probability level must be thoroughly familiar and usable with facility. Their use must be integrated with that of all the other techniques available throughout the planning, execution and evaluation of the project and they must not be considered simply as the last stage in the handling of the resulting data. Properly employed they make possible considerable savings in material for samples, in time required for the work in expense of equipment, in segregation and tie-up of machinery.

Statistical methods have been widely accepted in textile research work and are gaining a recognized place in manufacturing of yarn and fabric. In manufacturing, however, there remains a problem of education for the personnel using them and also (and this is less widely appreciated as to importance) for the executive personnel who must base decisions upon them. An extraordinarily versatile and powerful tool, statistical analysis is proving it's value to the textile industry and already is a measure of progress in modern manufacturing and research.

REFERENCES:

1. Abbott, N.J. – Text. Res. Jl., Vol. 21, No. 6, June 1951.

2. Ashcroft, A.G. – Text. Wld., Dec. 1943.

3. Beall and Jorgensen – Text. Res. Jl., Vol. 21, No. 4, April 1951.

4. Beckwith, O.P. – Text. Wld., Jan. 1944

5. Rudnick, E.S. – Text. Res. Jl., Vol. 20, No. 10, Oct. 1950

6. " " " Text Wld., Vol. 101, No. 10, Oct. 1951.

7. " " " Text Ind., Vol. 116, No. 2, Feb. 1952.

8. Schwarz and Winn – Am. Dye. Rep., Vol. 28, 1939.

9. " " " Am. Dye. Rep., Vol. 29, 1940.

10. Thomason, W.A., Jr. – Text. Wld. Vol. 101, No. 1, Jan. 1951.

11. Wakeham and Wakelin – Text. Res. Jl., Vol. 20, No. 9, September 1950.

12. Wakeham and Spicer – Text. Res. Jl., Vol. 21, No. 4, April 1951.

13. Whitwell, Leniska and Hughes – Text. Res. Jl., Vol. 21, No. 8, Aug. '51.

14. Whitwell, Bowen and Toner – Text. Res. Jl., Vol. 20, No. 6, June 1950.

15. Williams, Vlases and Fielding – Text. Res. Jl., Vol. 20, No. 10, Oct. '50.

QUALITY CONTROL IN THE TEXTILE INDUSTRY

Gardner M. Hailes
Quality Control Manager
Avondale Mills of Alabama

Perhaps you have heard it said – that higher quality costs more. You may also have heard the direct opposite of this statement, to the effect that "Higher quality *really* costs less." The remarkable thing is that both statements can be true, depending upon which of the two basic meanings for the word "quality" the speaker has in mind. This distinction between these two meanings may be academic to a customer, who has no real reason to distinguish between them. But the distinction is a very real and practical one to a manufacturer, who has very cogent reasons for recognizing these two basic meanings.

The distinction is that better *design* quality costs more, but that better quality of *workmanship* costs less. This has been recognized by quality control people for some time.

For example, the design quality of a piece of really fine chambray is clearly different from sheeting. But the quality of workmanship in an imperfect or "second" sheet is different from its perfect counterpart. In the textile industry, a lot of money goes down the drain each year in the discounts given for seconds, and short lengths caused by imperfections. And however complex may be the chain of events which leads to a particular imperfection, taken as a whole, they reflect the quality of workmanship with which the goods are made. To paraphrase an old quality control maxim, "You can't burl and grade quality into a fabric, you must spin and weave it into the cloth."

As every older mill man knows, variation per se is the source of countless evils in any textile mill. When old mill men die, they may go to a special Valhalla where all yarn is perfectly uniform, where the relative humidity is unvaryingly ideal, and where the staple is entirely constant in its properties.

Unfortunately, in this imperfect world, there is variation in *all* things. Fortunately, once we have made this realistic admission, we find that this variation does itself follow some pretty definite patterns and laws, which if known, can be capitalized on. And that is where Quality Control comes into the picture. Your quality control man has at his disposal several excellent tools for analyzing variation into its principle trouble-making components. It is clear that a working knowledge of how to analyze variation in a quantitative manner would be a very useful thing to have around a textile mill, even if it is based upon a branch of mathe-

matics with an unfortunate name like "Statistics"!

Not only is this word hard to pronounce, but it conveys entirely the wrong idea to someone unfamiliar with the subject. To most people, "Statistics" means a simple tabulation of figures of questionable accuracy on some uninteresting subject, like the daily price of rice in China in the year 1939. Quality Control people use the word in an entirely different sense. We use it to refer to that branch of modern mathematics which deals with probability, laws of chance, analysis of variation, etc. It is this science which has fashioned for us the mathematical tools of modern Quality Control.

One of these tools is the so called "Control Chart" which was devised by Dr. Walter Shewhart in 1926. This is a means for analyzing data so as to determine at once if a process is headed for trouble. It is based on the fact that a certain definite amount of variation is perfectly natural, normal, and unavoidable, but any variation beyond this definite amount is strong evidence that something has gone wrong with the process, or is about to do so. This is a very elementary description of this powerful tool, which has several other valuable properties such as the presentation of voluminous data in a manner that can be absorbed at a glance by a busy man. It can also be used to determine what a process *is capable of doing*, even though the process was not actually at its best when the measurements were taken. It can answer such questions as "How close is my finishing process capable of holding cloth width?" or "How close can the mill hold yarn count?" The fact that the Control Chart is based on some rather high-powered mathematics need not detract from its usefulness.

There are several other modern "statistical" methods which can be very helpful in obtaining, analyzing, and presenting data. These include a technique for analyzing variation into its component parts so that the major sources of variation can be discovered and worked on first. They include a method for analyzing the effect of one or more process variables upon a quality characteristic in which you are interested. They include methods for designing relatively fool-proof mill experiments, and for extracting the maximum amount of information from the test results. They include methods for summarizing voluminous test data so that a busy mill executive can "get the story" at a glance. They include methods for determining whether a difference in the values of two averages, such as average yarn strength before and after making some change in the process, is a real difference, or might easily be due to chance variation.

It should be emphasized that these statistical methods are not substitutes for good engineering judgment, experience, or common sense.

These methods are really only tools, that should be used as required, with discernment and imagination. When so used, they can be very helpful in tackling knotty quality problems.

This "statistical" aspect of modern quality control is mentioned at the outset because it is the least understood, or most misunderstood of all phases of the subject. Most of the other phases are as old as industry itself. You could probably find some of them in Ben Franklin's Almanac. The "modern" principle of prevention, which is one of the cornerstones of quality control, might be expressed there as: "A stitch in time saves nine," or "An ounce of prevention is worth a pound of cure." It is the chief function of a Quality Control Department, to prevent defects from happening.

And yet something new has been added even to these older principles. This is the fact that in a modern quality control set-up, all of these principles have been integrated into one effective tool. Which leads us to a definition of quality control, as: "The art of preventing defects from happening by using a specialized staff department which is skilled in the use of the objective engineering approach, and the modern tools of mathematical statistics." The textile industry generally, has not used staff departments as much as other mass-production industries. But in recent years there seems to be a strong trend in this direction in the textile industry, particularily in regards to Quality Control and Production Control.

It is well known that the quality of yarn affects the quality of the weaving. The quality of roving affects the quality of the yarn, and so on, all the way back to picking, opening, and cotton buying. So a program to realize the benefits of an improvement in the quality of workmanship must eventually get back to these preliminary operations. This involves those periodic tests of quality characteristics which textile control laboratories have been checking for years, such as staple length, strength, and fineness, uniformity of picker laps, nep counts, sliver, roving, and yarn size and evenness, yarn and cloth strength, etc. All of these test results will vary from day to day, from machine to machine, from bobbin to bobbin, and even within a bobbin. Since there is no inherant virtue in just making a lot of tests, it is necessary to know how much variation is normal for a given test, so that corrective action can be taken when and only when it is warranted. This is a job for the "Control Charts" mentioned previously.

Some people rebel against paper work to the extent that they will devote practically all of their time to testing, and none at all to analyzing and summarizing their data. Such people throw away much valuable information. Others may make a few tests, and attack these meagre data with exhaustive and time consuming analytical methods. Neither of these

two extremes is desirable. A proper balance must be struck between the time spent in gathering data, and the time spent in analyzing it. The simpler quality control techniques such as the Control Chart method, require very little time.

This is the day-to-day, or routine part of the quality control job. It involves the procurement and analysis of meaningful control data, the establishing of reasonable but definite limits of allowable variation, the following up of out of control tests to assure that corrective action is forthcoming, and the preparation of periodic summary reports for administrative use. The non-routine phases of the quality control job are perhaps even more important than these routing items. No doubt most members of mill supervision are perfectly capable of sustained long-range quality planning. But the chances are in most textile mills they simply don't have time to do it. It is in this area that a specialized staff quality control group can work with maximum effectiveness.

By analyzing defects, for instance, they may discover that the majority of off-goods are caused by only a handfull of types of defects. They can then assist in formulating an effective program to attack these causes at their sources. They can evaluate the quality of competitive goods in quantitative numerical terms. They can devise improvements in grading methods, such as the so-called "Point System of Grading," and follow through until these improvements are in effect. They can conduct mill experiments aimed at improving quality and lowering cost. They can determine the potential natural capability of a process in meeting a requirement, cloth width, for instance, and compare this with actual performance. They can devise practical ways and means of capitalizing on research results. Utilization of fibre fineness as a guide for buying and blending cotton is an example of this. Despite the fact that the textile industry is the oldest mass-production industry, it appears to us that there is at least as much work of this general nature to be done as in the mechanical, chemical, and process industries where quality control first proved its ability to get results.

In addition to these technical projects, there are others which fall in a non-technical or human catagory. Chief among these is the development of what Dr. J. M. Juran has named the "Quality Mindedness" of the employees. There are a great many things which can be done in this area. These things are most effective if they are welded into a program, and followed through with a systematic and sustained drive. The designing of such a program to suit the needs of a particular mill requires staff work and coordination which can be assigned to the Quality Control Department.

Following are some of the things which may be incorporated into

such a program: Determine the best weaver and the worst weaver from grading records. Give an award or other recognition periodically to the best weaver. Other mill departments may be included. Run a series of articles stressing quality and explaining various practical aspects, in the mill's paper. Publicize customer complaints and the reports of complaint investigations. Make up large but simple quality charts for posting in strategic spots in the mills. Use posters which emphasize quality. Conduct small group meetings with employees and supervisors, etc.

It is apparent that a full-fledged Quality Control Department can play an important part in the production of fabrics and in the lowering of production costs. Quality is of course a subject close to the heart of the Sales Department, as they must continually deal with the quality factor in their efforts to keep old customers and to get new ones. Quality may even be a factor in a mill's advertising program. One should hastily add, however, that a quality control program which is inaugurated for its advertising value is doomed from the start to be a dismal failure. The only defensible approach, and the only one likely to succeed, is a sincere desire to "deliver the quality", and a determination that this shall be done.

Statistical Quality Control, in its modern sense, originated in 1926 when Dr. Walter A. Shewhart of the Bell Telephone Laboratories first published a comprehensive paper on the subject. Most of those currently engaged in this field are engineers, of one sort or another, the majority of whom have probably had very little if any formal training in mathematical statistics. The rapid increase of interest by American industry in quality control and statistics is reflected in the formation and phenomenal growth of the American Society for Quality Control. In its existence of less than ten years, it has become a national society of over six thousand members. In recognition of the growing demands of the textile industry, the American Society has formed a Textile Division in order to be of maximum service to the textile industry.

Quality Control as a separate staff function, has existed at Avondale Mills for two years. The Quality Control Manager reports directly to the executive head of the company. We have a Quality Control Engineer at each of the larger mills, who reports directly to the Quality Control Manager on all technical matters. For geographical reasons, these men also report administratively to the local mill superintendent. Each Quality Control Engineer has a staff of one or more inspectors and one clerk, to perform routine tests and to prepare reports and analyses. The physical testing and chemical laboratories are also under the supervision of the Quality Control Manager.

The Manufacturing Department at Avondale, headed by Vice President and General Superintendent W. A. Turner, remains fully responsible for quality. The Manufacturing Department of course hires and trains the men, selects and maintains the machines, devises and supervises the operating methods. These three things, men, machines, and methods determine quality in the broad sense. By way of analogy, the Manufacturing Department is in the front lines in the constant battle to achieve maximum quality at minimum cost. The Quality Control Department is in the second lines of defense. It is our job to check the location and to analyze the shifts in the battle lines, to point out in a constructive manner any dangerous trends in the tide of battle, and to jump into any quality situation where we can do some good. In doing this, we use the modern methods of statistical quality control.

These new methods and techniques can be made to dovetail neatly with the older and more traditional methods. Each supplements the other, and the net result is a distinct improvement in effectiveness. Like anything new, it takes some selling to put it over. This selling is most effectively done by having the overseers and superintendents take an active part in the quality control program, which of course requires training to bring about their understanding of the basic principles involved. Management too can be of tremendous help in this "selling" phase of quality control by providing their full support of the program.

We are fortunate at Avondale in having this support in full measure. When J. Craig Smith recently took over as President of Avondale he said: "In the past we have always tried to deliver our customers full weight, full measure, and good quality. These policies are fundamental and will have the fullest support of which I am capable."

At the turn of the year he expressed the following in Avondale's house organ: "On behalf of the entire Avondale organization, we make the following three pledges to ourselves and to our customers:"

1. We will make it better.
2. We will make it better.
3. We will make it better.

We have customers who tell us that our quality is now second to none. We will not be happy or satisfied until every customer that we do business with is so minded."

A properly integrated Quality Control Department, with a definite and comprehensive program, can be very helpful in implementing such policies, and in capitalizing on the fact that "Better quality really costs less."

TOLERANCES FOR COTTON FIBER STRENGTH DATA

M. Earl Heard[1] and W. S. Smith[2]

The standard procedure for measuring cotton fiber strength employs a Pressley Tester. Immediate results are expressed in pounds breaking strength per milligram of bundle weight and is referred to as the Pressley Index. This index may be translated to breaking strength in pounds per square inch or 1000 p.s.i. by using an empirical equation: 1000 p.s.i. = 10.80 P.I. – 0.1200.

Testing technique requires a degree of operator skill that may differ from operator to operator, and from time to time with the same operator. Also, results may be affected by machine differences and variations in general testing conditions. To reduce operator drift and standardize technique, a check sample is used as a bench mark. Specimens from this check sample are tested at the beginning of the day and at intervals thereafter to determine the quality level of the operator technique.

Quality control charts (Fig. 1) can be used very effectively. Persistent differences from quality standard and drifts in operator technique are graphically revealed. In addition to plotting individual results, it is also desirable to plot the averages of each ten consecutive breaks. Averages usually reveal trends better than individual values.

Usually an operator can modify her technique in order to correct trends that develop. Persistent differences in quality level may be due to the testing instrument or to a personal equation. If the cause cannot be found and corrected, a correction factor should be applied to all results from that source in order to adjust them to the required level.

Statistical tolerances for these control charts are indicated as broken lines on each side of the center line, which is the standard or grand average. 2 Sigma tolerances alert the operator and 3 Sigma tolerances demand a correction. Statistical tolerances are calculated from the short term variation recorded by one operator upon specimens from the same sample. for instance, each operator makes two or more consecutive tests upon each bale sample submitted for testing. Because of the short interval of time between tests, there is small chance that the difference between values is due to operator drift or mechanical causes. This short term discrepancy thus reveals the inherent variation that exists in the testing technique.

[1] *M. Earl Heard, Vice President in charge of Research, West Point Mfg. Co.*
[2] *W. S. Smith, Research Division, West Point Mfg. Co.*

Table 1, although incomplete, illustrates the nature of these data, which were obtained from 200 pairs of results observed during routine testing. Each pair of values represents a single bale sample. The 200 different bales samples were submitted to a single operator over a period of time. When only the difference between paired results is considered, bale differences are eliminated, and inherent variation only is measured.

$$\text{Short term or inherent st'd. dev.} = \sqrt{\frac{\text{Sum(difference)}^2}{2k}} = 0.120 \text{ Pressley Index}$$

k = number of bales or pairs of results

±2 Sigma limits individual values = ±2×0.120 = ±0.240 Pressley Index
±3 Sigma limits individual values = ±3×0.120 = ±0.360 Pressley Index
±2 Sigma limits average 10 values = ⅘(1.028×.120) = ±0.082 Pressley Index
±3 Sigma limits average 10 values = 1.028×.120 = ±0.124 Pressley Index

Note: Equation: 3 Sigma limits = $A_1\bar{\sigma}$: When $n = 10$, $A_1 = 1.028$.

(In one instance, out-of-tolerance in the case of an operator caused an investigation that discovered lint in the ball bearings of the carriage of the testing instrument. When corrected, test values were again in tolerance.)

Table 1. Paired Results One Operator

Bale #	Test Results #1 P.I.	#2 P.I.	Difference P.I.
1	7.21	7.28	.07
2	7.46	7.54	.08
3	7.42	7.66	.24
4	6.98	7.08	.10
5	7.81	7.63	.18
6	8.04	7.88	.16
7	8.19	8.05	.14
8	7.24	7.26	.02
9	8.03	8.25	.22
10	7.30	7.24	.06
$k = 200$	6.89	7.04	.15

$\text{Sum(difference)}^2 = 5.7692$

$2k = 400$

Variance = 5.7982/400 = 0.014423

St'd. Dev. = $\sqrt{0.014423}$ = 0.120 Pressley Index

Fig. 1, which is a control chart upon the laboratory check sample used as a bench mark, shows some drift in operator technique. Although the chart helps her to make necessary adjustments before a drift becomes serious, the fact remains that long term variation does exist. It is affecting results from routine testing, as well as her check testing. Tolerance

for routine test results must be based upon the long term variation recorded for the check sample. In this particular set of data, the long term standard deviation on the check sample is 0.151 Pressley Index.

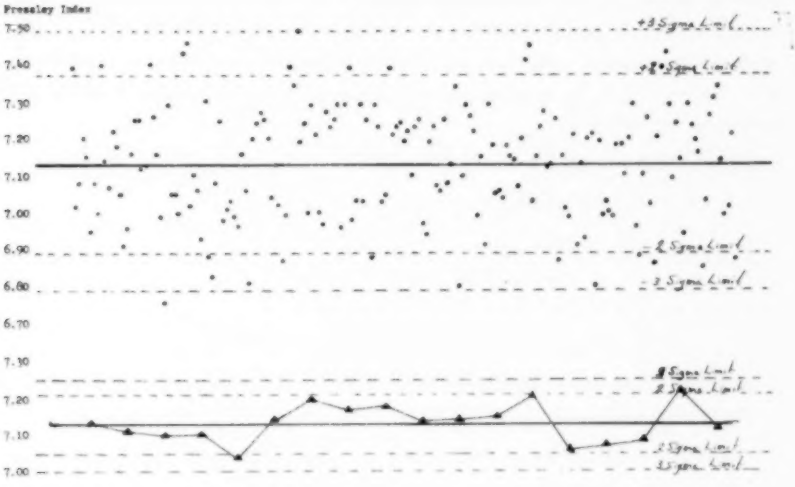


FIGURE 1 – Control chart for operator on bench mark sample.
Upper chart is for individual results.
Bottom chart is for consecutive average of 10 results.

A common laboratory practice is for two operators to work as a pair, each breaking one specimen per bale sample. Ten bales from each shipping lot are usually tested in this manner, and the operators compare their averages at the completion of each lot. This practice has certain psychological advantages. Also, a periodic comparison of operator results helps to detect drift or out-of-control technique and reduces the number of reference to the control. A tolerance is needed for this comparison.

3 Sigma limits = $\pm A_1\bar{\sigma}$; $A_1 = 1.028$ when $n = 10$.

2 Sigma tolerance = $\pm\frac{2}{3}(1.028\times0.151)$ = ±0.104 or 0.208 Pressley Index

3 Sigma tolerance = $\pm1.028\times0.151$ = ±0.155 or 0.310 Pressley Index

Operator difference greater than 0.21 P. I. suggests that both operators check themselves on bench mark sample for drift. An operator difference greater than 0.31 P. I. dictates that the lot be retested after operators have corrected their technique, or a correction be applied to the biased result. If two operators do not have the same long term testing error, the tolerance based upon the larger long term standard deviation should be used.

A laboratory may select samples from 20 bales per lot and assign 10

bales to each of two operators, requiring one test specimen per bale. In this case, there is a sample difference between operators that must be included in the tolerance. This sample difference will be unknown, but its value depends upon the amount of variation in fiber strength from bale to bale in the same lot. An average variance obtained from past experience, however, can be used. Assume, for example, that bale-to-bale differences within the average shipping lot have a standard deviation of 0.10 Pressley Index. This is equivalent to an actual range of about 5,000 p.s.i. between bales.

Sample Variance = $V\omega + nVb$

$V\omega$ = testing variance or $(0.151)^2$

Vb = bale variance or $(0.10)^2$

n = no. tests per bale = 1

$(nk = 1 \times 10 = 10;\ A_1 = 1.028)$

St'd. Deviation = $\sqrt{0.0228 + 0.01} = \sqrt{.0328} = 0.181$ P. I.

2 Sigma tolerances = $\pm\frac{2}{3}A_1 \times$ St'd. Dev. = 0.248 P. I.

3 Sigma tolerances = $\pm A_1 \times$ St'd. Dev. = 0.372 P. I.

When the cotton merchant laboratory and cotton mill laboratory have independently drawn bale samples and tested, the tolerance for laboratory disagreement must also include a tolerance for sample difference, as well as a tolerance for testing. Consider two 10-bale samples independently drawn, where a pair of operators in each laboratory tests 2 specimens per bale, or 1 specimen per operator per bale.

Sample Variance = $V\omega + nVb$

$V\omega = (0.151)^2$

$Vb = (0.10)^2$

$n = 2$

$nk = 2 \times 10 = 20;\ A_1 = 0.697$

St'd. Deviation = $\sqrt{0.0228 \times 2(0.01)} = \sqrt{.0428} = .207$ P. I.

2 Sigma tolerance = $\pm\frac{2}{3} \times 0.697 \times .207 = 0.192$ P. I.

3 Sigma tolerance = $\pm 0.697 \times .207 = 0.288$ P. I.

Now consider two laboratory samples of 20 bales each. Two operators at each laboratory test 1 specimen per bale and divide the 20 bales equally between themselves, or 10 bales per operator. $n = 1;\ k = 20;\ nk = 20;\ A_1 = 0.697$.

$V\omega = (0.151)^2$

$Vb = (0.10)^2$

St'd. Deviation = $\sqrt{0.0228 + 1(.01)} = \sqrt{0.0328} = 0.181$ P. I.

2 Sigma tolerance = $\pm\frac{2}{3} \times 0.697 \times 0.181 = 0.168$ P. I.

3 Sigma tolerance = $\pm 0.697 \times 0.181 = 0.252$ P. I.

Reference should be made to 1951 issue A.S.T.M. Standards on Textile Materials Appendix IV, and A.S.T.M. Manual on Quality Control. The substance of this paper is a specific application of the proposed recommended practice outlined therein. Data used in this illustration should be considered applicable only to the operators and laboratory from which it was obtained.

Summary:

	No. Tests n − k	St'd. Dev. P.I.	Tolerance			
			2 Sigma		3 Sigma	
			P.I.	1000 p.s.i.	P.I.	1000 p.s.i.
(1) Short term - 1 operator	1 - 1	0.120	0.480	5.17	0.720	7.66
(2) Short term - 1 operator	10 - 1	0.120	0.164	1.65	0.247	2.55
(3) Long term - 1 operator	10 - 1	0.151	0.208	2.13	0.310	3.23
(4) Sample - 1 operator	1 - 10	0.181	0.248	2.56	0.372	3.90
(5) Sample - 2 operators	2 - 10	0.181	0.192	1.95	0.288	2.99
(6) Sample - 2 operators	1 - 20	0.181	0.168	1.69	0.252	2.60

QUALITY CONTROL IN COTTON MIXING

J. B. Denmark *

Paper Presented before Georgia Section of A.S.Q.C.

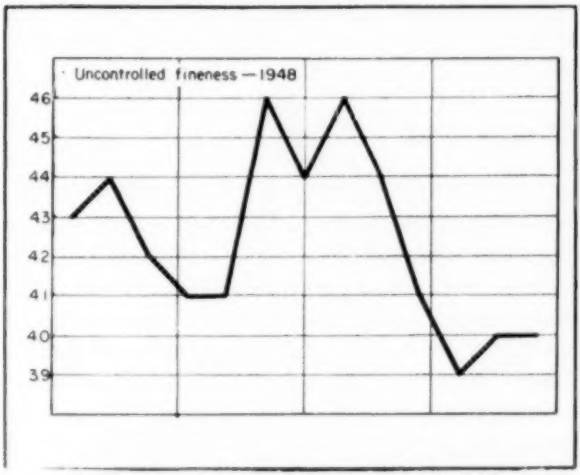
In the last several years, we in the cotton textile industry have come to know and appreciate the importance of the various properties in the raw material from which we manufacture textiles. Previously mills were operated strictly on a staple and grade basis with little or no consideration for such properties as fineness, fiber strength, maturity, or fiber distribution. The cotton was probably bought by some person not directly concerned with manufacturing and it was up to the mill to run this stock regardless of whether it met the mill's needs or not. Today, however, when costs of raw material and labor are continually rising, the Quality Control Laboratory is in a position to improve quality, increase production and prevent "blow-ups" through the selection and use of cottons best suited to the individual mill's needs. All of this can be accomplished with little or no extra expense. Of course the needs of one mill are naturally different to those of another and depend entirely upon the finished product, but regardless of whether your product is tire cord, broadcloth, industrial fabrics or feed sacks, an intelligent use of the various fiber properties in cotton will pay big dividends.

For the purpose of this discussion we will consider only the application of cotton fineness to the mix, since it is a property that can be easily measured and has a tremendous effect on quality, strength and manufacturing performance. For those of you who may not be familiar with the term fineness, it might be well for us to discuss it briefly. Fineness is expressed as the mean weight in micrograms of one inch of cotton fiber, therefore, if we have a cotton that is 4.2 in fineness, the mean weight of one inch of cotton fiber would be 4.2 micrograms. Fineness is influenced by two factors: first, cell wall diameter which is a direct function of the type cotton, Asiatic cottons generally having a large diameter, American Upland cottons having a medium diameter and Sea Island or Egyptian cottons having a small diameter. The second factor influencing fineness is cell wall thickness which is dependent on variety and weather conditions. Since most of us are using one type of cotton, say American Upland, cell wall thickness is of more importance than cell wall diameter. By the end of the first two or three weeks of the growing season the fiber has reached its maximum length and diameter and then begins to add cellulose to its walls. If the fiber is able to develop thick walls it is coarse, if not it is fine.

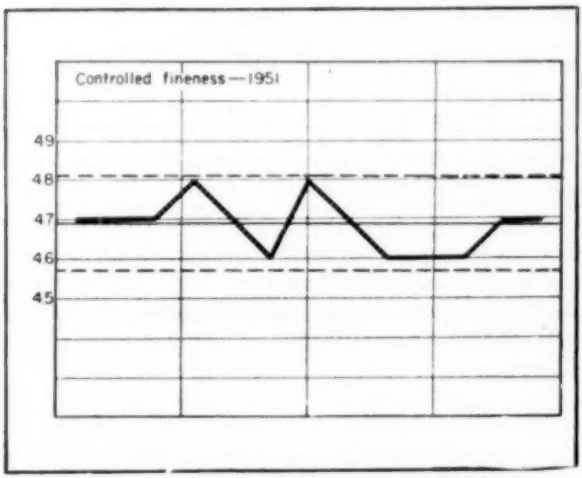
* *Laboratory Supervisor, Pepperell Manufacturing Co., Lindale, Ga.*

For the last several years we have been gathering background material with fiber testing and have gradually established a program whereby almost every mix is made up from cotton selected on a fineness basis. We began with one of our most important filling mixes going into a style of goods requiring a reasonably low nep count. Coarse fiber from various grades was ear marked for this mix and the results from this first venture were so satisfactory that gradually we have been applying it to other mixes.

CHART 1

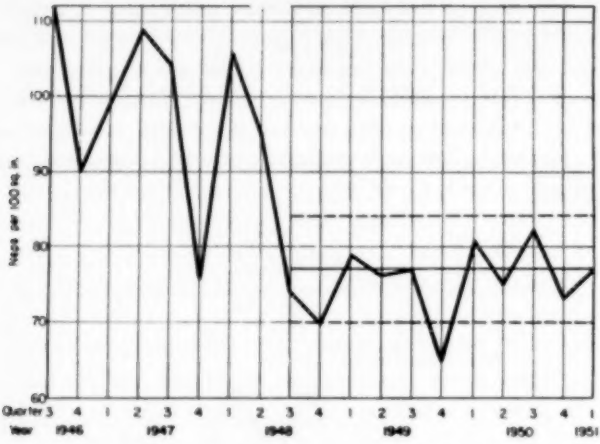


First 3 months of 1948 – Uncontrolled Mix



First 3 months of 1951 – Uncontrolled Mix

CHART 2



Cloth nep count before and after controlling mix

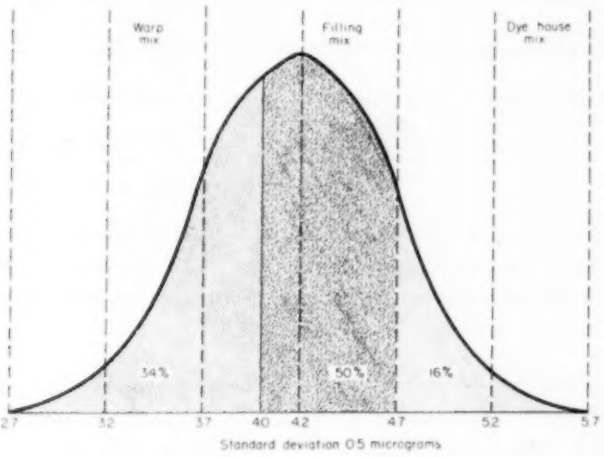
It might be interesting to describe our present procedure for selecting and running mixes with controlled fineness. As cotton arrives it is taken to the receiving warehouse to be weighed, classed and checked for fineness. The Cotton Laboratory, located in this warehouse, checks every bale on the Micronaire and then separates the various grades and staples into the correct mix relative to fineness. We have found it to be advantageous to check every bale for fineness since any one grade of staple may go into any of several mixes depending upon the fineness. From the receiving warehouse, all stock is put into permanent storage by grade, staple and fineness. It is then easily accessible for making up individual mixings.

Obviously grade and staple are still a dominant factor for economic as well as manufacturing reasons, therefore we must necessarily conform to certain grade and staple requirements in applying fineness to the mixes. The range in fineness of cotton going into a particular mix determines largely just how the individual mixings will be made up. Should this range be low, then all cotton will be put in one fineness group and the bales taken at random for the individual mixings. On the other hand if the range is wide due to the quantity of cotton needed for a mix, it may be necessary to divide the cotton into several fineness groups, taking a percentage from each group to make up each mixing. This method generally provides satisfactory fineness control.

In a program such as this, it is necessary to establish a satisfactory quality level based on customer demands as well as the availability of stock to produce the desired quality.

Outlets must also be found for the undesirable fineness levels as it is impossible to reject all of the fine cotton and use only coarse stock in order to maintain a desired quality level. There is also an economic feature to this, since the cotton merchants are now beginning to include fineness when quoting prices. As an example let us consider three of our mixes made from a mixture of 15/16" and 1" SMG, MS, SLM, and SLMB. From analyses of shipments in previous years we may expect the standard deviation of fineness to be .5 micrograms. Based on this years 4.2 mean, we have established the following program.

CHART 3



Warp Mix: Can conceal neps by fine fiber. Fine fibers add strength in manufacturing. Pick up low fineness from other grades to balance needs. Using cotton 2.7 to 4.0.

Filling Mix: Low nep count as a result of coarse cotton. Using cotton 4.0 to 4.7.

No. 2 Dyehouse: Low nep count and even dyeing as a result of very coarse cotton. Using cotton 4.7 to 5.7.

The chief advantages of controlling fineness are:

1. Consistency of mix:
   - A. Maintain quality level – less testing
   - B. Maintain twists & mechanical set-up
   - C. No "blow-ups"

D. Improves manufacturing performance

E. Increase production

2. Improve Quality

A. Reduces neps better

B. Cleaning – coarse cleans better – possibly cut down on waste

C. Improves dyeing

From our experience we are fully convinced that a program of cotton testing is very worth while and will mean much to the industry as a whole.

CAN GOOD SLIVER BE IMPROVED

W. V. Hassett
Quality Control Engineer, Martha Mills Division,
The B. F. Goodrich Co.

People of the Textile Industry feel that their quality control problems are among the most perplexing in all of manufacturing. Perhaps quality control managers of every other industry feel the same way about their problems, but lacking proof to the contrary, we contend that the behavior of billions of fibers, as they progress from the bale through the various stages of manufacture into the finished fabric, presents the most baffling combination of variables to be found anywhere.

The variables referred to could be grouped broadly as follows:

1. Variation in raw material (i.e., physical properties of fibers).
2. Non-uniform distribution of fibers in the yarns.
3. Defects in yarns or fabrics.

It is not the purpose of the present discussion to go into the first and last of these classifications, and we will try to develop only a few basic ideas on the second item, the Non-uniformity of fiber distribution in the yarn.

This lack of uniformity of fiber distribution results in variation of the cross sectional diameter of the yarns, which will be referred to in the following discussion as simply "Variation". The degree of variation normally encountered in cotton yarns would range from 8% to 30%, mean linear deviation, depending upon the size of the yarn, raw material, and the efficiency of its manufacturing processes. Figure 1 shows graphically how a yarn varies in its cross sectional mass, as shown by the electronic evenness tester.

The variation in the yarn shown in Figure 1 is the result of these two simple conditions:

1. There is variation in the stock fed *into* the spinning process and
2. There is variation introduced *by* the spinning process.

This, of course, is elementary, and is common knowledge with all textile men. And every textile man also knows that excessive variation in the roving being fed into the spinning frame makes it virtually impossible to produce quality yarns. Now, with the common practice of spinning from single creel roving, and that roving in turn having been produced in one process directly from the finished drawing sliver, without the aid

of doublings at either stage, we are confronted with the fact that the evenness of the sliver is of extreme importance.

Figure 2 shows the type of variation normally encountered in finished drawing sliver. Note the section A–B, which represents only 4" of sliver which varies from 13% above to 15% below the average. This section of the sliver would draft out into approximately 400" of yarn as shown in Figure 3. It will be noted, of course, that while many new short term variables have been introduced at the roving and spinning processes, the central line has moved from 13% above to 15% below the average in close agreement with the original sliver variation.

This is also a fundamental fact that is generally accepted, and is repeated only for the purpose of emphasizing the great need for better understanding of sliver variation, since only through better understanding can we expect to do much toward improving this condition.

In Figure 4 a series of charts are presented which have been drawn purely on a theoretical basis, illustrating how some of these variables *might* occur, and how they could combine to produce the final effect. This *had* to be done on a theoretical basis, since in order to present these different effects, it is necessary to eliminate all other variables, especially the variable nature of the material being fed into the process. For example, Figure 4A indicates the chart of a perfect sliver from a drawing frame using perfect creel slivers, a condition which is, of course, impractical if not impossible.

Now refer to Figure 4J. It will be generally agreed that this is more representative of actual drawing sliver variation as shown by a Saco-Lowell sliver tester. For reasons to be given later, this particular curve is not drawn to the same horizontal or vertical scales as are commonly used on either the Saco-Lowell or other type testing equipment, but in a general way it does resemble the erratic sort of curve of Figure 2, which is an actual test chart.

Without referring to Curves B through I in Figure 4, how would you diagnose the causes of the variation in Curve J? In the first place, if it did not exceed your tolerance or go "out" on your control chart, and you attempted to determine the cause of the excessive variation by studying the chart, it is doubtful if you would arrive at the correct answer. Until recently it has always been our opinion that this erratic type of variation was due largely to the variable nature of the stock entering the process or to the inherent weakness of the roller drafting system. Now we are not quite so sure that this type of variation is not due in large part to mechanical discrepancies in the drawing frame which could be eliminated or certainly improved.

In order to illustrate this assertion, Curves B through I of Figure 4 represent the variation which would be introduced if the "perfect" conditions of Curve A were upset by irregular drafting resulting from eccentricity in each of the 8 drafting rollers.

Curve J is the resultant curve from the mathematical combination of all of the 8 curves above it. In order to facilitate the plotting of these curves, only 26-5 inches of sliver was used, representing the longest repeat from the system (the circumference of the back bottom roller multiplied by the draft). The vertical amplitude of each of the curves B through I has been held to the same value and no vertical scale is indicated on the chart. The main reason is that we do not have a definite relationship between roller eccentricity and its effect upon variation. We do know, however, that the resulting variation is considerably greater than the relatively small changes in roller surface speed which are produced by the eccentricity. For example, a front steel roller which has .010" eccentri- is considered quite bad, and would produce a highly variable sliver (perhaps 4% to 6% above normal) and yet its surface changes speed by only ±0.4%.

This exaggerated effect is probably due to the many secondary reactions between the fibers in the drafting zone, a subject which we will not attempt to explain here. We do know, however, that this secondary action varies greatly with type fiber, draft, roller spacing, and bulk of fibers being drafted.

The charts shown in Figure 4 are concerned only with the surface speed changes which result from eccentricity in the drafting rollers. In addition, there are 12 gears in the drafting system, each of which is capable of producing the same type of irregular roller surface speed. A gear which is slightly imperfect will produce a curve similar to those shown in Figure 4, except, of course, that each gear would produce a wave of slightly different frequency in the final sliver. If one assumed only a slight imperfection in each of the 12 gears and the 8 rollers, the cumulative effect would present a variation curve of such extremely erratic nature that it would be almost impossible to make an intelligent analysis of the causes of the variation by studying the chart.

If any one gear or roller is bad enough, it is easily detected, either on the frame or in the variation chart. The object of this discussion has not been to call your attention to these extreme conditions, but rather to invoke some thought as to how the generally accepted "normal" sliver with 20% variation might be reduced to 10%.

Next time you see a sliver variation curve, think of the 20 or more

ormal/Inert Test Irreg: % Date:

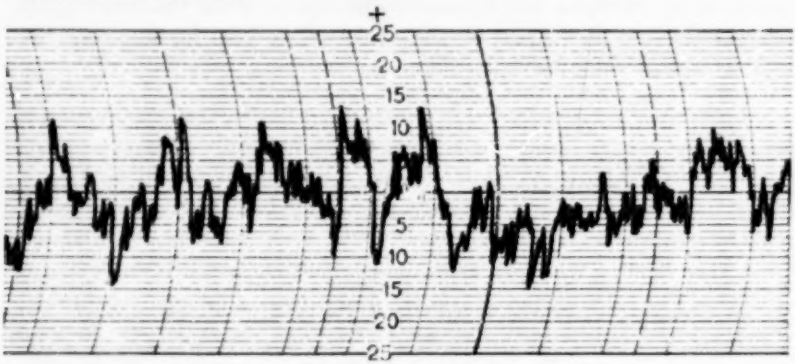


FIGURE 1

mal/Inert Test Irreg. % Date:

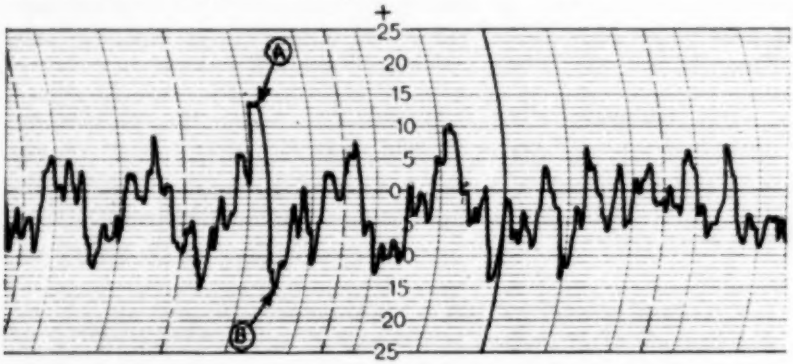


FIGURE 2

mal/Inert Test Irreg. % Date:

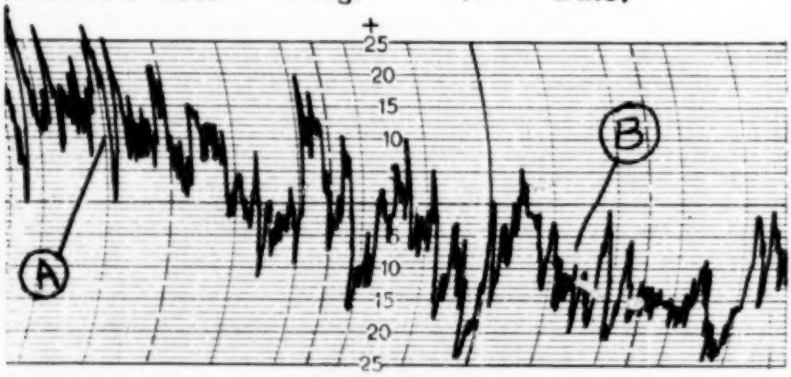


FIGURE 3

relatively small sine waves which added together to produce it. Then try to do something about the "small" things; the big ones will take care of themselves.

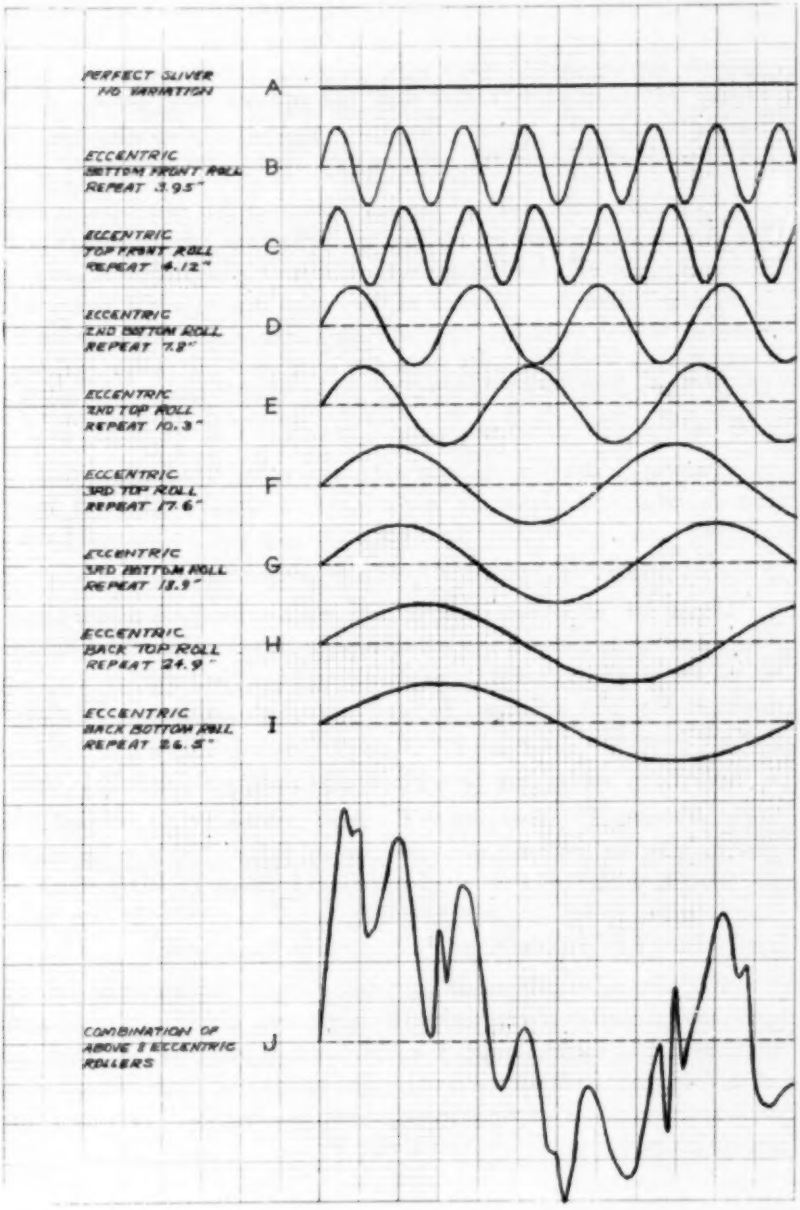


FIG. 4

CONTROL OF STOCK SIZE AT DRAWING FRAMES

M. Earl Heard * and C. G. Bramlett **

Statistical quality control methods have improved long-term uniformity in stock size, and also taught a new lesson about a very old textile process. Improvement in stock size uniformity was accomplished by reducing the variation in actual draft between standard metallic 4-roll drawing frames. The lesson learned was that actual draft depends upon the effective diameter of the rolls, as well as upon the draft gear.

In this particular case, cotton stock receives two processes of drawing. All breaker frames and all finisher frames had the same draft gears and were supposedly producing the same average grains of stock per yard. Stock size control was directed at the roving frames, which is the next process. Control measures were not satisfactory. Gear changes on the roving frames were frequently needed to keep stock size within arbitrary limits. One creel of finisher drawing might produce light roving, and the next creel produce heavy roving.

Drawing frames were brought under inspection. Draft gears, tension, roll weighting, moisture regain, and other factors were investigated. None of these seem to be causing the trouble. The next step was to check stock size at each drawing frame before and after processing.

Stock size was determined at each frame once daily for five days. Daily averages were determined from two-yard sections from each delivery of the frame. These five daily averages were used to calculate the frame average. Also, the difference between the highest and lowest daily average per frame gave the range within that frame.

Fig. 1 is the graphic record of these tests. Each dot represents a frame average. The center line is the grand average weight per yard. The broken lines are the upper and lower control limits. They were calculated by statistical methods that will be explained later. The interpretation of these charts is that all frame averages should be within the boundaries of the broken lines; otherwise, the process is out of control.

Engineering investigation and measurements did not show any appreciable variation in size of the drafting rolls. Measurement of actual draft by comparing the length between two designated points before and after drafting showed very definite frame differences. These actual draft measurements had a strong inverse correlation with stock size from each

* *M. Earl Heard, Vice President in charge of Research, West Point Mfg. Company, Shawmut, Alabama*

** *C. G. Bramlett, Standards, Langdale Mill Division, West Point Mfg. Company, Langdale, Alabama*

frame. Actual draft is related to the effective diameters of the fluted rolls, which depends upon the degree the flutes mesh and crimp the stock. According to a machine manufactory handbook, the effective diameter of a 1 3/8 " fluted back roll is 45% greater than its measured diameter. Also, a 1 1/8 " fluted front roll has an effective diameter 20% greater than the measured diameter. Apparently, any one of a number of factors can produce a difference in effective diameter, with an effect equivalent to one or more teeth in the draft gear.

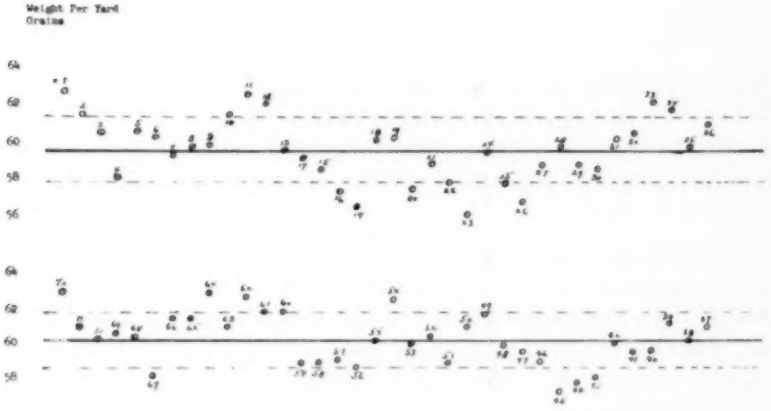


FIGURE 1 – Sliver weight per yard at beginning of study.
A. Upper chart: Breaker drawing frame.
B. Lower chart: Finisher drawing frame.
Each dot represents a frame average obtained from 5 daily weighings.

The solution was to change draft gears until the frame average grain per yard was within the statistical tolerance. Because stock is channeled between breaker and finisher frames, it is necessary to adjust the breaker frames first, and then obtain new frame averages for finisher frames before adjusting them. Fig. 2 shows the final results. After an interval of six months, the frames were still within the statistical limits.

Tolerance for drawing frame averages must consider mechanical limitations as well as a tolerance for sample variation. Machine draft is adjusted stepwise by changing draft gears. On these particular frames, a difference of 1 tooth in the draft gear produced a change of approximately 2 grains per yard in sliver weight. When draft gear changes are used to adjust the frames, a mechanical tolerance of ±1 grain per yard must be allowed.

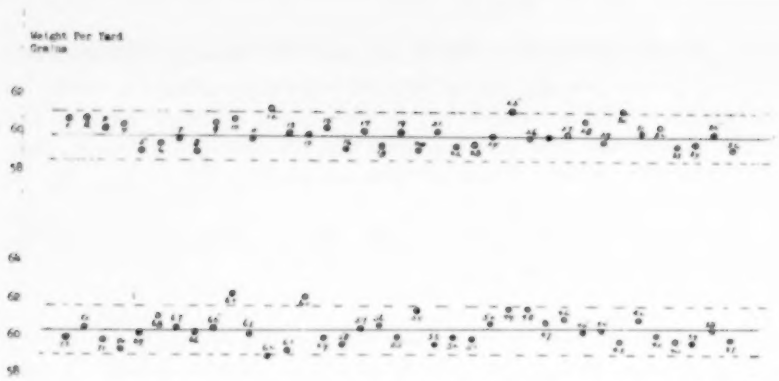



FIGURE 2 – Sliver weight per yard under control.
A. Upper chart: Breaker drawing frame.
B. Lower chart: Finisher drawing frame.
Each dot represents a frame average obtained from 5 daily weighings.

Sample tolerance = $\pm A_2\bar{R}$. A_2 is a constant obtained from a quality control handbook. Its value varies according to the number of tests. For five tests per frame, $A_2 = 0.577$. $\bar{R}$ is the average range in stock size between five weighings per frame. For breaker frames, $\bar{R} = 2.70$ grains, and $\pm A_2\bar{R} = \pm 1.565$ grains. For finisher frames, $\bar{R} = 2.05$ grains, and $\pm A_2\bar{R} = \pm 1.185$ grains.

Using the data for breaker drawing to illustrate, the statistical tolerance for breaker frame differences were calculated as follows:

$$T_0^2 = T_1^2 + T_2^2$$

$$T_0^2 = (1.0)^2 + (1.565)^2 = 3.443$$

$$T_0 = \pm 1.86$$

T_0 = Over-all tolerance
T_1 = Mechanical tolerance
T_2 = Sample tolerance

WAMSUTTA'S QUALITY CONTROL PROGRAM*

Edward S. Rudnick.
Director of Research, Wamsutta Mills**

As in most cotton mills, quality control at Wamsutta breaks itself down into four classes:

a. Control of the raw cotton by the Cotton Department

b. In-process controls by roving departmental quality inspectors

c. Cloth room and finished goods 100% inspection

d. Laboratory controls (embracing all of these).

Since only the last of these classes deals with statistical quality control techniques as the Q.C. Engineer knows them, this paper will outline what Wamsutta's Quality Control Department has done in this respect. Specifically three such statistical tools are utilized, (1) process control charts, (2) significance testing, and (3) analysis of variance.

The first step in the setting up of a quality control system should be the determination of where the major variations are occurring and of what characteristics should be controlled. In determining these, general analyses of variance for each of the major manufacturing processes are valuable aids. At Wamsutta such analyses have been made of the yarn (its size and strength), the roving, the draw sliver, the comber sliver, the comber noil, and the card sliver.

In making a general analysis of variance, all variables and interactions considered to be important are taken into account. The final conclusions show which of these variables and interactions have a significant influence on the particular process. The variables and accountable interactions capable of being controlled are placed in control. But of more value is the fact that the results indicate which are the important variables to take into account in future sampling. For instance, from the yarn analyses, the variation between the positions on a bobbin was not found to be significant. This indicated that it was not necessary to wait for the doff to sample bobbins in the future.

Variables other than those being considered should be minimized. In taking into account the variable of days of the week, it is necessary that the same source of the product (i.e., the roving in the case of the spin-

* *Some portions of this paper are from a paper by the author, "Statistical Quality Control at Work in a Cotton Mill", Textile Reasearch Journal, Vol. XX, No. 10, October 1950.*

** *New Bedford, Massachusetts*

ning frame, or the sliver in the case of the slubber) be used throughout the test, assuming that the variation between bobbins or cans on the previous process is not significant until proved otherwise in a separate analysis.

After it had been decided, with the help of such analyses, which processes were to be controlled, it was necessary to determine what sample size to use for each process. This was done by computing the average coefficients of variation both from past records and from the data of the general analyses. Tables such as those recommended by Committee D-13 of the A.S.T.M.[1] were used. To determine which "allowable random sampling error" to use, the overseers concerned were asked whether they would accept any conclusions drawn as being correct 19 out of 20 times (or whatever other probability they desired).

Forms were then made up for the collection of data to comprise the populations on which the quality was to be based. In some cases past data were used for this purpose. In the case of the yarn, the items controlled were the mean size, the range of the size, the mean strength, and the range of the strength for each count each day. For simplicity of calculations, ranges were used instead of standard deviations.

These yarn charts are based on the English System of control limits rather than the American "three sigma" system. Inner control limits are used at the 2.5% level and outer control limits at the 0.1% level.[2] The area between the two sets of limits is called the "Warning Region". Thus although five times in each 200 a point will fall in the "Warning Region" due to chance alone, the probability of two successive such points being due to chance is slightly greated than six times in 10,000. Using the straight three sigma limits, such points would probably be considered "in control".

For the roving process, it was decided to use four bobbins from each frame each day, while using one average and range chart for each type of roving. Thus if on one day there are three frames on a single type roving, then the sample size is twelve. Accordingly there are three sets of control limits on each of these average and range charts (in different colored pencil) to indicate the limits for sample sizes of four, eight, and twelve. In the case of the $\bar{X}$ Charts, the narrowest limits are for the largest sample size, while the reverse is true on the range charts.

[1] *Committee D-13 A.S.T.M. Standards on Textile Materials - - Appendix V, Proposed Recommended Practice for Calculating Number of Tests, Philadelphia 1949.*

[2] *Brownlee, "Industrial Experimentation", Brooklyn, Chemical Publishing Company, 1948.*

Almost from the beginning the control charts were warmly received. The superintendents and overseers observe the trends periodically. But the controls do not stop there. Daily reports interpreting the charts are distributed to the general manager, the superintendents, and the overseers. The factors being controlled for each count of yarn are reported in columnar form as, "Weak, Out of Control," "Warning Region Light," etc. When five points in succession fall on the same side of the mean, where the probability is 1/32 that this is due to chance alone, this is reported as "Continues Heavy, Within Limits"; "Continues High-Range, Within Limits"; etc. Also, weekly reports are made for each item, giving the percent of "Good," "Warning Region," and "Out of Control" points so that the over-all quality records of a department can be compared from week to week.

The material value of such reports is obvious, particularly if all "Out of Control" places are starred in red and if the reports are distributed the same day that the samples are taken. However, the psychological value is also great, since the overseers know that the men above them are reading the same report. The results manifested themselves in the following ways: almost all the ranges showed consistent downward trends; the weekly reports showed definite increases in the percent "Good" and decreases in "Out of Control"; ends-down in spinning and weaving decreased; experienced mill men found themselves speaking in terms of ranges; many investigations were made to determine why certain factors had gone out of control; and everyone became more quality-conscious.

This method of controlling the quality has been made flexible for easy revision. A running record of the daily means and ranges is kept so that every few months the charts can be revised and the limits narrowed to fit the new quality standards.

Besides the process control charts on Yarn and Roving, Wamsutta also uses $\bar{X}$ and R Charts on the Finisher Drawing and Ribbon Lap processes - - Wamsutta being almost a 100% combed cotton mill. For the first year or two of this program, all the testing was done in the Laboratory and all the charts maintained in loose leaf fashion on a large slanted table top. A system of cross reports was installed whereby each production gear change was reported to the Lab. and these noted on their resspective charts in the form of arrows up or down to denote "assignable causes of variation."

Then certain modifications were made. After a couple of revisions of the roving it was noted that this process ran almost continually in control with very rarely any need for gear changing. Instead of further narrowing of the control limits, it was decided to reduce the frequency of

testing from every day to twice a week.

To get more rapid and closer control of the two key processes - - ribbon lap and drawing - - the testing was taken out of the Laboratory and back into the mill. Now these machines are sized twice each shift and the averages and ranges immediately plotted on a separate control chart for each machine. Only when the point falls beyond the control limit (as verified by an immediate check size) is the gear on that machine changed. The Quality Control Department supplies the charts with the limits already on them. Since the time this system was installed, the number of gear changes on these processes has actually been reduced and yet the product on the subsequent processes is more even.

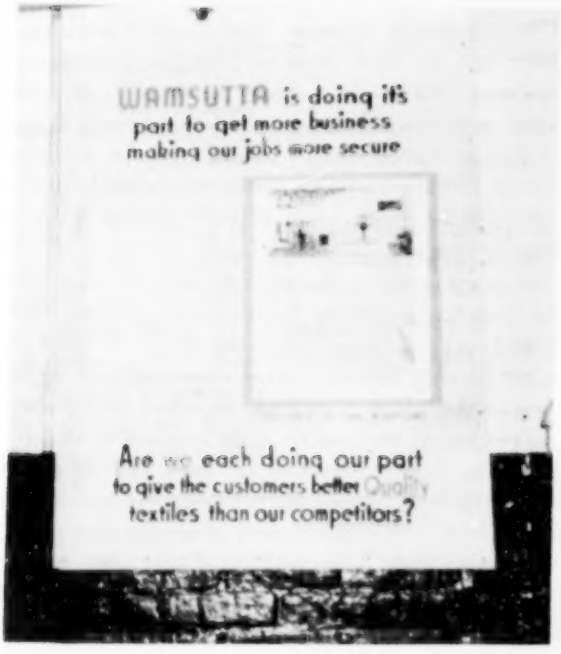
At present, besides the Spinning Mill precesses, $\bar{X}$ and R Charts are maintained for different styles of greige and finished cloth strengths, for departmental waste records, and even on the accident frequency charts of Wamsutta's Safety Department. p Charts are maintained on the Percent Seconds found by each group of inspectors in the Sheet Factory. And c Charts are used for the Quality Level Data from the sampling inspection of sheets, towels, and finished goods ready for shipment.

Besides these routine S.Q.C. tools, Wamsutta's Quality Control Department uses significance tests whenever two sets of data are being compared. For instance, these tests have been applied[3] to yarn strengths, sizes, and break factors on yarn spun in different rooms, from different rovings, with different staple lengths or different twists to fabric tensile and bursting strengths from the same roll, different rolls, different lots and different competitors; to nep count data before and after stripping the cards or from different lots of cotton; to yarn or roving before and after the installation of a new part to a processing machine, etc.

Finally, as mentioned in the beginning, Wamsutta uses the tools of variance analysis and correlation analysis to determine the significant variables affecting particular processing machines.

Thus, by means of the above outlined program, a 106 year old textile organization has found the relatively new science of Statistical Quality Control to be helpful, successful, and valuable.

[3] *"Can You Trust Averages?", Edward S. Rudnick, Textile World, October 1951.*


WAMSUTTA is doing it's
part to get more business
making our jobs more secure
Are we each doing our part
to give the customers better Quality
textiles than our competitors?

Aside from the control laboratory itself, Wamsutta's Quality Control Department is concerned with quality mindedness amongst the workers. A sample of the types of posters used to emphasize this is illustrated. Such posters are used throughout each production department.

QUALITY CONTROL IN A WEAVE ROOM

Mary Jo Wesson, Statistician
Research Division, West Point Mfg. Co.

The function of a weave room is the weaving of cloth. The prime concern of the weave room overseer can be expressed in one sentence – "Keep the looms running and make the cloth good." Production and quality can not be separated. The production must be there to have the goods to sell and the quality must be there so that the goods will sell. The problems of producing a quality fabric are multitudinous. The looms must be kept in good repair, the weavers must be adequately trained as well as the loom fixers, battery hands, pickout hands, smash hands and any others working in the room. There are the problems of personnel. The fixer does not like his weaver or vice versa and they do little things to aggravate each other which in turn has its effect on the work produced on the job. No two people are exactly alike or react to situations alike. No one will deny the truth of this that has ever tried to coordinate the efforts of several individuals necessary to keep the average stand of looms producing at a high level making cloth of good quality. Besides the personality differences, there is the problem of adequately trained personnel– the "know-how" of doing the particular job in question. There is also the problem presented by certain individuals of getting the individual to take an interest in doing a job to the best of his or her ability. These are but a few of the problems confronting the weave room overseer. Pages could be devoted to outlining the details of his job. It is in a situation such as this that the chart technique of presenting data becomes valuable.

The cry "Keep the production up" has been heard by mill men in every department for many, many years. Various schemes have been tried to encourage the employees to produce more and more. Some have been successful and some have not. But before anything can be done about production, the overseer must first know what is his production and where it is lagging and where it is not. No man can keep data in his mind that covers a period of weeks. Nor can he keep in his mind the fluctuations in that data. A certain amount of variation in production is due to chance causes. No weaver will keep her looms running the same amount of time each week. Maybe a high percentage of her warps ran out at the same time. Maybe she had a loom breakdown that took hours for repair. All of these things hurt her production record but certainly can not be blamed on her weaving technique. An overseer with more than one weave room under his supervision certainly needs the help of charts to keep him aware of his production and the variation in that production. The charts discussed below were designed with this purpose in mind.

These production charts are simple x-bar charts on individual data. In the weave rooms in question the production is expressed as a percentage. This has been the practice for many years and all the people involved are accustomed to thinking of production in this manner. The standard deviation was computed for each room and the limits are the usual 3–sigma limits. On these charts will be found a second set of limits. These are the 2–sigma limits or the 95% level. The 2–sigma limits are used as a warning signal. This is especially true on the lower side. Any climb in production is naturally very welcome.

The chart in Fig. 1 shows the per cent production for a particular room over a twenty-week period of time. The chart was started about two weeks after a big change was made in the type of fabric being woven. Just after the style change the per cent production went hay-wire. Various reasons can be advanced and probably all these reasons contribute to the general upset. The chart shows a steady rise in production over the entire period. For this period there is an actual total variation of 3 per cent. The expected variation based on this data ($\pm 3\sigma$ limits) is 5 per cent.

The chart in Fig. 2 shows subsequent data for the same room, same shift after new control limits had been calculated. The average production increased one per cent over the prior period. The most significant feature of this chart is the decrease in the amount of variation. For a period of 15 weeks there was an actual variation of 1.50 per cent as compared with the 3 per cent of the previous period. The expected variation based on this data was 2.50 per cent as compared with the 5 per cent of the previous period. The variation was decreased 50 per cent to an acceptable amount. The next improvement is to bring the room average to a higher level with no increase in variation. The last seven weeks on the chart in Fig. 2 shows that this is being accomplished.

Fig. 3 and 4 show the production charts for another weave room on two shifts. Compare the two charts. There is a two per cent difference in the average per cent production. However, most of this is due to the fact that the first shift's looms are started about 15 minutes before the shift is scheduled to begin – an advantage not enjoyed by the second shift. The most significant difference between the two shifts lies in the range in variation. The total variation expected for shift #1 is 4.92 per cent while the total variation expected for shift #2 is 6.08 per cent. An investigation revealed that the first shift had a supervisor with many years of experience running a section. This supervisor had the "know-how" of getting the most from the machinery and the people. The supervisor for the second shift doesn't have the background of experience of the first supervisor. This is the ideal working combination – to have a young supervisor follow an older, more experienced man. They, themselves, benefit by the rela-

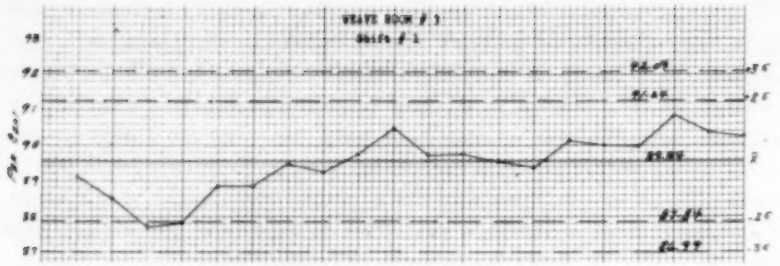


FIGURE 1

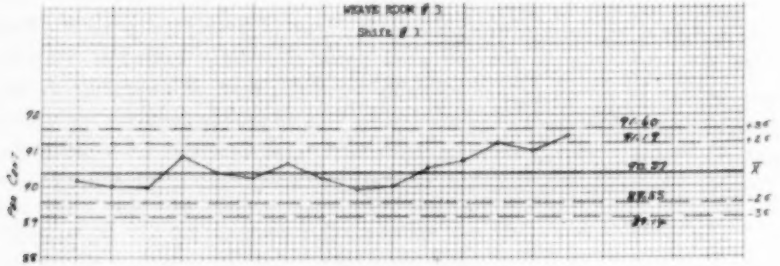


FIGURE 2

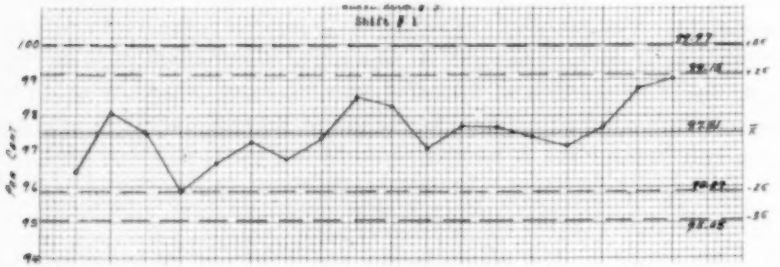


FIGURE 3

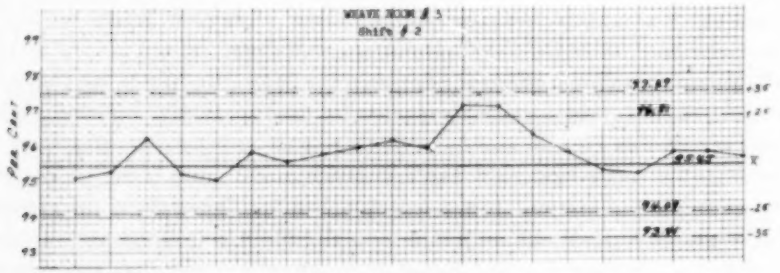


FIGURE 4

tionship as well as the room which comes under their combined supervision.

The task of keeping a production chart on each weaver is very impractical. However, when a room's production is not as it should be, the chart technique can be used to study individual weavers for a short period of time. The table below shows the data and calculations made for such a study. Fig. 5 shows the resulting chart.

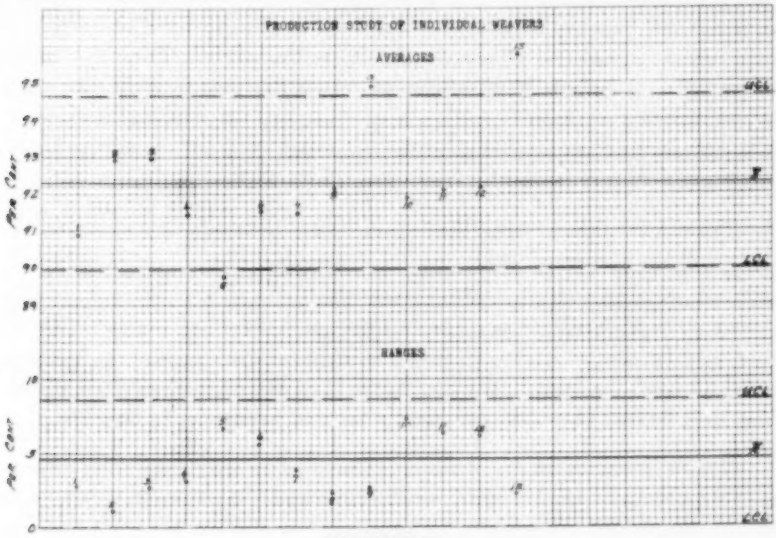


FIGURE 5

PRODUCTION STUDY OF INDIVIDUAL WEAVERS

Weaver	------ WEEKS ------						
No.	1	2	3	4	5	Aver.	R.
1	89.51L	90.62	91.44	90.45	92.37H	90.88	2.86
2	92.39L	93.44H	92.74	93.12	92.93	92.92	1.05
3	92.23L	92.48	92.68	92.46	94.90H	92.95	2.67
4	90.00L	91.59	90.28	92.16	93.09H	91.42	3.09
5	85.86L	88.44	91.35	90.62	92.49H	89.75	6.63
6	89.15L	90.62	91.51	91.62	94.70H	91.52*	5.55
7	88.86L	91.41	92.06	92.29	92.74H	91.47	3.88
8	91.31	92.25	91.20L	92.43	93.49H	92.14	2.29
9	95.15	95.43	92.91L	95.51H	95.40	94.88	2.60
10	94.78	90.59	87.57L	91.55	94.90H	91.88	7.33
11	89.43	88.76L	92.60	94.56	95.14H	92.10	6.38
12	89.55L	91.04	91.49	92.99	95.72H	92.16	6.17
13	95.69	95.26	95.66	95.03L	97.27H	95.78	2.24
				Average:		92.30	4.06

$\bar{X}$ = 92.30	$\bar{R}$ = 4.06
UCL = 94.64	UCL = 8.59
LCL = 89.96	LCL = 0

Examination of the table shows that all except two weavers had their highest production of the period under observation on the same week. All except five had their lowest production on the same week. This naturally leads one to ask the question as to why practically all the weavers in one room would follow the same trend. The answer obviously will be found in the general running conditions at this particular period. There are times "when the work runs bad" with several possibilities as to the cause. The weather conditions, room temperature and humidity, condition of the warps, strength of the yarns all contribute to the general overall running conditions.

The chart drawn from the above data presents an even better picture of the weavers. There are three weavers whose production averages are outside control limits – weavers 5, 9 and 13. The rest of the averages are about the same. A prior study of these same weavers showed none outside control limits. Weaver 5 is ordinarily a fair weaver. Weavers 9 and 13 have the best "stands of looms" on the section and one of the best loom fixers. They also are ideally located in respect to humidity.

The differences in the weavers show best in the range chart. There are five weavers whose range in variation is above 5 per cent. With a chart of this nature the supervisor can show each weaver how he or she compares with the other weavers of the section. The supervisor can accurately determine which weavers are having trouble and where he should be spending his time to improve the room average. The supervisor shows the chart to the weavers and the loom fixers since both are responsible for keeping the looms running. But the supervisor has to find his way through a maze of excuses to get at the source of trouble. There has never been a weaver who was at fault for low production and all loom fixers always keep their looms in good repair. Sometimes the mere showing of the chart to the employee brings the production up. More usually there are a combination of causes for the variation in production that requires the teamwork of all concerned to correct the condition.

The same type of study can be made on the per cent seconds. Fig. 6 shows a chart made from a study of eleven weavers – five of whom did average work and six of whom are considered below average. An examination of the chart will readily show which are average and which are not. Generally, the supervisor follows the same procedure as on the production study except that he inspects thoroughly the looms producing the most seconds. It is his duty to improve the existing conditions.

Another method of making the employees quality conscious is the use of a chart locating seconds according to looms. The chart has drawn on it small squares representing the looms of a certain section. The loom numbers are written in the squares just as they are located in the section. When there are seconds on a loom, pins with large colored heads are stuck in the square representing that loom. Each type of seconds has its own color of pin. These charts are placed in a case in each weave room where all may come and inspect the seconds record. In connection with this chart, a card index is kept of the loom and the seconds made on each loom. If one type of seconds comes up twice in succession on the same loom, the shift supervisor is notified of the loom number and the type of seconds. That this type of chart is a success is proven by the fact that two weavers were heard discussing why a loom was making seconds and what to do about it while standing in front of one of these charts. Even heated arguments have taken place.

These are only a few of the approaches that can be used in controlling the quality in a weave room. The success of any program rests with those doing the job. If the right approaches are used along with sound techniques, the weavers themselves will be the best quality control men the weave room overseer can possibly have.

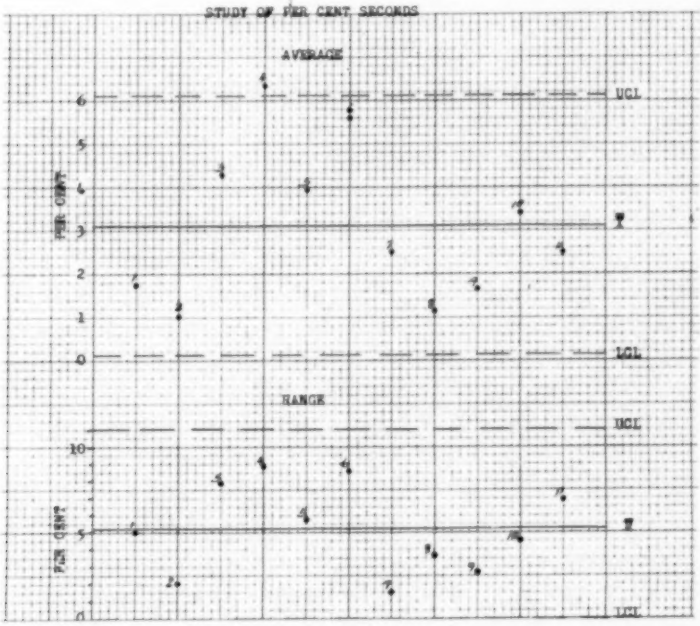


FIGURE 6

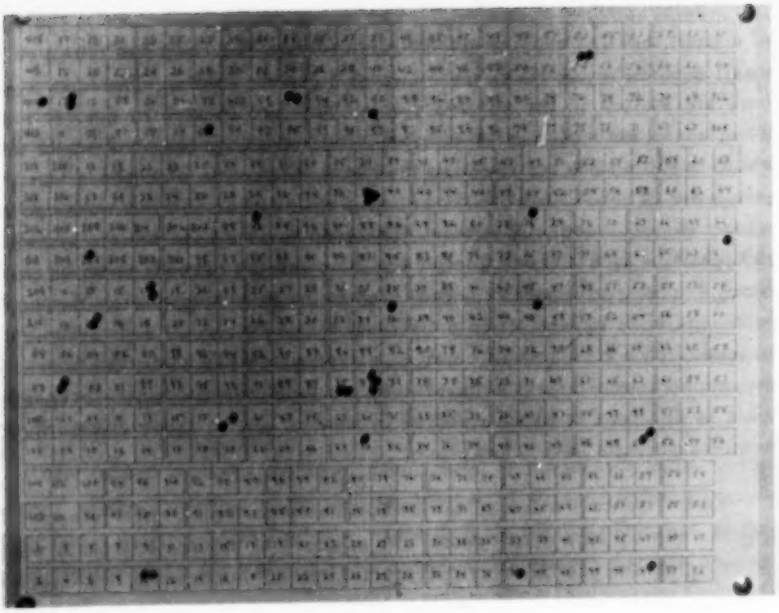


FIGURE 7

APPLICATION OF STATISTICAL METHODS TO WEAVING AND INSPECTION

H. A. LeDuc *

INTRODUCTION

The first phase in any system of cloth quality control is to check that the fabric meets its physical specifications, such as weight, width, thread count, breaking strength and the like. In most cases it is not practicable to measure the characteristic concerned while the cloth is on the loom. Short lengths must be cut off and taken elsewhere for inspection. We are therefore forced to build our control system on the basis of measurements of samples which represent a very small portion of the total volume of material being produced.

Process control of cloth specifications thus presents an ideal application for statistical techniques. Control charts for averages may be set up for each characteristic for each style of cloth. The variability of each is determined experimentally, and suitable control limits are computed. The results of each individual measurement, or the average of a small group of measurements (e.g., the average of two warpwise or five fillingwise breaks on a single one-yard sample) are plotted on the proper chart. Until a reading falls outside of the control limits, no further sampling or corrective action is indicated.

The measurement of conformance to physical specifications is, however, but a small portion of the whole problem of weave room control. The major task is the inspection for cloth defects. To avoid the production and accumulation of large quantities of second quality fabric, it is necessary that major defects be discovered as quickly as possible, traced as to source and cause, and that remedial action be taken promptly.

To this end, every mill maintains a cloth room, where each roll of cloth, labelled as to style and loom on which it was woven, is given 100% inspection. Inspection standards and techniques will vary widely, according to the end use of the fabric and the mill's own standards of quality. Inspection may consist merely of scrutiny by the shearing machine operator, while the cloth passes by at high speed. More commonly, it will involve passing the cloth slowly over special inspection tables, where inspectors will both note the defects and repair many of them.

Regardless of the type of cloth, or of the mill's quality standards, the principle is the same. Instead of sampling inspection, subject to the laws of statistical probability, we have an application of 100% inspection,

* *Manager, Magog Division, Dominion Textile Co. Ltd., Magog, Quebec.*

and subject to the often less predictable laws of human behaviour.

In statistical terminology, the reasons that statistical techniques are unsuitable for this application are two-fold. Many cloth defects are critical, and cannot be tolerated. Corrective action is required immediately. Secondly, most of these defects are not random in the statistical sense. Often due to faulty loom adjustment, they constitute an assignable cause of deviation from standard, and, once produced, will continue to occur at regular intervals until either weaver or fixer takes suitable action.

When we shift the scene of inspection from the weaving department cloth room to the inspection room of a finishing plant, or of a large cloth consumer, however, our point of view is radically different. In most instances, each piece of cloth will have lost its identity insofar as the conditions of weaving are concerned, and we are merely interested in determining whether a given piece of cloth, or a lot of cloth, is acceptable as first quality or whether it must be classified as a second. Assuming the cloth has been produced under controlled conditions, the prerequisites for a statistical application now prevail. A reasonable number of defects are expected and will be tolerated, and their occurrence, from our new point of view, is random in distribution.

A STATISTICAL APPROACH TO FINISHED CLOTH INSPECTION

In the following we will consider a statistical approach to the control of quality in the inspection and folding room of a finishing plant.

The grey mill has previously inspected each piece of cloth as it came from the loom. A point grading system is used. Under this system, defects are classified as 1, 2 or 4 points in value, according to the seriousness of the defect. Defects grading in excess of 4 points are either cut out of the piece, or result in the entire piece being classified as second quality in the grey. The inspectors are trained to recognize the various types of defects, and record them on a tally sheet as they find them. The total points per piece are converted to points per 100 yards of cloth, and this figure is marked on the cloth.

Whenever a predetermined value is obtained or exceeded, the piece is classified as second quality, and segregated from the first quality goods. A typical tally sheet is shown in Fig. 1.

The finishing plant thus is assured that all goods shipped to them as firsts do not exceed this predetermined value insofar as grey mill defects are concerned. The task of the finishing plant therefore is to inspect for its own defects, and to check that these, plus the defects originally in the grey cloth, do not exceed the desired quality level.

CLOTH GRADING SHEET

Style N-124 Grade ~~1st~~ 2nd S/E

Loom 31 Yards 212½

Date JULY 1/52 Insp. J.P.D.

	No.	DEFECT	1st	2nd	3rd	Cut Out 1st	Cut Out 2nd	Cut Out 3rd
FILLING	1	Broken Pick	4					
	2	Kinky Fill.		2				
	3	Mixed Fill.						
	4	Pulled in Fill.		2				
	5	Slubs	2					
	6	Stuffed Fill.	2 4					
	7	Thick Bar	4 4					
	8	Thin Bar		4				
WARP	9	End Out	4 4					
	10	Float	4					
	11	Hitchback	4 2	4				
	12	Hole	4					
	13	Reed Mark						
	14	Wrong Draw	4					
MISC.	15	Oil or Rust	4 2	2 2				
	16	Temple Mark					5	
Total Pts./Shift			52	16		5 Yds.		
Grand total Pts.			68/207½ Yds.			33		

CLOTH ROOM OVERSEER:

Repeat ☐ Repeat of Same Defect ☐

2nds TO WEAVE ROOM:

Overseer's Comments: _____

Weaver Overseer

FIGURE 1

Inspection in the finishing plant is carried out in the following manner. The cloth is passed over a folder or "hooker" at a rate of approximately 100 yards per minute. The folder operator is expected to see all critical faults, and to mark them by inserting a small rag into the fold containing the defect. The piece is then passed on to a hand inspector, who rapidly spot checks the cloth for lesser faults by turning over the laps. As she comes to the defects previously flagged she takes action, usually by cutting out, or by pasting on an allowance sticker. This operation of "hand lapping" is shown in Fig. 2.

FIGURE 2

The portion of each piece to be inspected will be determined by experiment, and will depend on the urgency that each individual piece of cloth be guaranteed as within the upper quality limit. Common practice ranges from 17% (every third lap, one side of cloth only) to 50% (every second lap, both sides).

DETERMINATION OF VARIABILITY

Before we can set up our inspection plan, we must learn certain vital facts about the material we are inspecting. The first is the variation in point value from piece to piece. This can most easily be determined

by studying the grey mill records. The standard deviation in point value between the random pieces of the same style of grey cloth will be designated by σ_b

The next statistic required is the variation between the true point value of the finished piece and the apparent value obtained by the inspector's estimate. This can be obtained by having a team of inspectors grade a few dozen pieces with extreme care, checking every yard. Not only is each defect recorded, but its position in the length of cloth is noted. Then, the corresponding values which would have been obtained had the regular inspecting technique been used are determined from the data sheet. For example, if the inspectors are expected to inspect every other lap, on one side of the cloth only, the points recorded for the first, third, fifth and every other yard throughout the length can be taken off and added. The total is converted to points per 100 yards, and compared with the corresponding figure under 100% inspection. The difference between the sampling plan value and the true value for each piece is determined. The standard deviation of this tabulation of differences is then obtained. This value represents the error in the inspector's estimate of the true point value, and is represented by the symbol σ_ω

THE SAMPLING PLAN

Let us assume that we have a cloth which is to be sold as "40-point" merchandise. That is, each piece should not exceed a defect point value of 40 points per 100 yards. Examination and calculations based on grey mill and folding room inspection tests have provided us with values of 10 points for σ_ω and 8 points for σ_b. Fig. 3 shows how these data are combined into a sampling plan for final inspection.

About a line at 40 points, which is the upper control limit (U.C.L.) for individual pieces, two other lines have been drawn. One has been drawn at a level = $1 \times \sigma_\omega$ below the U.C.L.; in this example, $40 - (1 \times \sigma_\omega) = 30$ points. The other has been drawn at 1.65 σ_ω, equal to 16.5 points, above 40. The area between these two new lines is known as the area of uncertainty. Any piece which the inspector grades as 30 points or less on her sample inspection is passed for shipment. Any piece which grades at 56.5 points or more is immediately classified as second quality. All pieces falling between these two levels are set aside for a 100% reinspection.

The objectives of a sampling plan of this nature are to guarantee control of quality with a minimum of inspection cost. If inspection of every other lap, on one side of the cloth only, proves adequate, then the cost of this operation is approximately only 25% of what it would be if the inspectors were required to look at every lap, both sides. Thus, if the

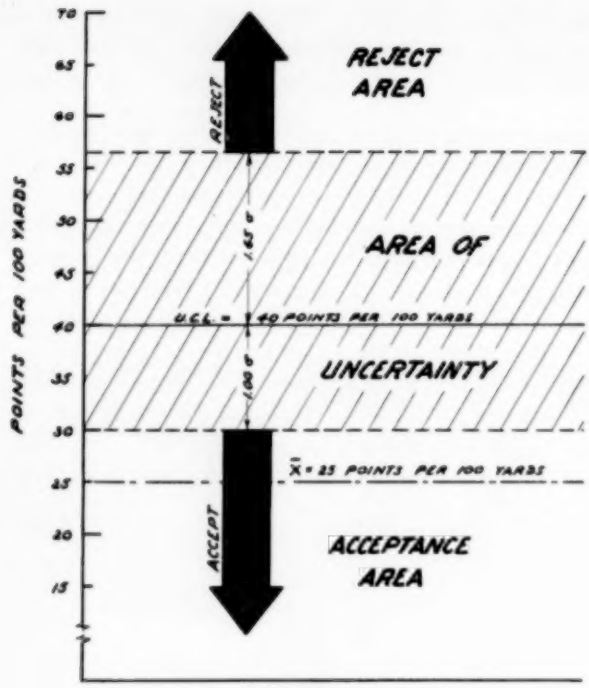


FIGURE 3

number of pieces falling into the uncertain area represent less than 75% of the total, the sampling technique represents a saving over a straight 100% inspection plan. The amount of savings will increase as the percentage of pieces falling into the area of uncertainty decreases.

EFFICIENCY OF THE SAMPLING PLAN

Table I shows the probabilities of having to reinspect cloth, because it has fallen into the area of uncertainty. It will at once be seen that the greater the difference between the average point value of the lot and the upper control limit, the more satisfactory and economical will be this sampling plan. In actual practice, it will be found that the number of seconds will become prohibitive long before the sampling plan becomes uneconomical.

Table II shows the efficiency of this plan, from the producer's point of view. Due to the uncertainty introduced by the sampling technique, there is the possibility that pieces which are graded at 30 points or less by the inspector will actually grade higher than 40 points, and therefore should be rejected. As seen from Col. B in the table, the probability that samples rated 30 actually exceed 40 points is fairly high. However, when

the probabilities of this column are combined with the probabilities of Col. C, we see that the chances of actually shipping a piece in this level is much smaller. This is because, for any reasonable level of process average, there will be only a fairly small number of pieces exceeding the upper control limit anyhow. Further explanation of these data are shown in the legend under the table.

The actual sampling plan which will be applicable to a given problem will vary considerably from plant to plant, and between various groups of styles within a plant. A few comments on variation in plans may be helpful.

TABLE I

PROBABILITIES OF REINSPECTION FOR VARIOUS PROCESS AVERAGES

Average Value of Lot	Point % Accepted First Inspection	% Diverted for Reinspection	% Rejected First Inspection	Probable % Seconds in Lot
15	97.0	3.0	0.0	negl.
20	89.4	10.6	0.0	0.3
25	73.4	26.6	0.0	1.7
30	50.0	50.0	0.0	6.7
35	26.6	73.1	0.3	19.1
40	10.6	87.7	1.7	40.1

The data in the above table are based on the following premises, as given in the example described in the text:—

Std. Deviation between Pieces, σ_b = 8 Points
Maximum Point Value for Acceptance = 30
Minimum Point Value for Rejection = 57
Minimum Point Value for Second Quality = 42

TABLE II

SAMPLING PLAN EFFICIENCY

A	B	C			D		
		Probability of Occurrence for Indicated Process Average			Probability of Shipping for Indicated Process Average		
Observed Point Value	Probability of Passing a Second.	$\bar{X}$ = 20	$\bar{X}$ = 25	$\bar{X}$ = 30	$\bar{X}$ = 20	$\bar{X}$ = 25	$\bar{X}$ = 30
30	11.5%	4.4%	5.7%	6.1%	0.5%	0.7%	0.7%
28	8.1	5.3	6.0	6.1	0.4	0.5	0.5
26	5.5	5.4	6.1	5.8	0.3	0.3	0.3
24	3.6	5.8	6.1	5.4	0.2	0.2	0.2
22	2.3	6.1	6.0	5.3	0.1	0.1	0.1
20	1.4	6.1	5.7	4.4	0.1	0.1	0.1
			TOTALS		1.6%	1.9%	1.9%

NOTES

1. Col. A lists various point values observed by the inspectors, which would cause a piece to be passed on for shipment.

2. Col. B indicates the probability that a given piece, with the indicated point value in Col. A as obtained by sampling inspection, would prove to grade 42 points or higher if given 100% inspection.

3. Col. C shows the proportion of total pieces in a lot which will have the observed point values of Col. A, for three different levels of process average.

4. Col. D is the product of Col. B and the data in Col. C. It indicates the probable proportion of total pieces in a lot which would actually be shipped out in excess of the specification limit.

5. Data in the above table are based on the following assumptions:- Std. Deviation between pieces within a lot, σ_ω 8 Points; Std. Deviation within pieces, due to saml ling error, σ_ω 10 Points; Acceptance Number = 30; Min. Point Value for Second Quality = 42.

If experimental data indicate that σ_ω is lower than shown in this shown in this example, a higher acceptance number may be set, thus reducing the area of uncertainty.

The reason for setting the upper limit of this area at $1.65\sigma_\omega$ is to minimize the possibility of rejecting a piece which would, on 100% inspection, prove to be first quality. It is usually cheaper for a mill to reinspect and possibly find some short lengths of first quality within a piece than to declare the entire length a second.

Under controlled conditions, the probabilities of finding pieces grading higher than $1.65\sigma_\omega$ above the U.C.L. are very slight. Therefore, since the cost of reinspecting this category will be very small, the supervision may feel that the plan will be simpler to administrate if the goods are divided into two classes only – acceptable for shipment and held for reinspection.

The sampling plan and the data shown in Tables I and II are built from consideration of the probabilities as determined from various values of $^{x}/\sigma$, as given in tables of areas under the normal probability curve. Once the principle under the example given is understood, a plan to meet the requirements of any specific situation may be tailor-made by reference to such a table.

TWO TEXTILE APPLICATIONS OF THE CHI-SQUARE CONTROL CHART*

John H. Reynolds
Celanese Corporation of America
Rome, Georgia

The author wishes to acknowledge the assistance received from Prof. R.J. Hader, Department of Experimental Statistics, N.C. State College, in editing and proof-reading this paper.

Chi-Square and Its Distribution

It is well known that a control chart may be prepared for any statistic provided a confidence interval is known for the statistic. The confidence interval is, of course, computed on the basis of some assumptions concerning the character of the distribution of the statistic and the individual members of the population which is being studied. The statistic, index of divergence, usually denoted by χ^2, is in some instances a very useful one to plot on a chart as a control measure. Such a control chart was suggested by Shewhart in his book *Economic Control of Quality of Manufactured Product*. It was also discussed by A. J. Duncan in an article titled A CHI-SQUARE CHART FOR CONTROLLING A SET OF PERCENTAGES in Vol. VII, No. 3 of *INDUSTRIAL QUALITY CONTROL*. The purpose of this paper is to discuss the χ^2 control chart and to exhibit some of its applications.

The index of divergence, χ^2, is defined as,

$$\chi^2 = \sum \frac{(c - \bar{c})^2}{\bar{c}}$$

where c is the observed frequency of a certain class, $\bar{c}$ is the expected frequency of that class, and the summation extends over all of the classes. It is seen that χ^2 is the sum of the relative squared divergences from the expected values. The distribution of χ^2 is known, and tables are available which give values of χ^2 at various probability points. The distribution of χ^2 is dependent only on the number of degrees of freedom associated with its calculation. If the number of degrees is n, and if control exists, that is, if there are no assignable causes of disagreement between the observed distribution and the expected, then χ^2 will be distributed with $\sigma_{\chi^2} = \sqrt{2n}$ and average n.

A paper presented at the Spring Meeting of the Georgia Section of American Society for Quality Control, Atlanta, Georgia, June 1, 1951.

For a fixed sample size it is fairly obvious that the better the fit of an observed set of frequencies to expected values, the smaller will be the value of χ^2

It is the usual practice in control charting to place limits at plus and minus three standard deviations from some target value, but this does not mean that it is necessary to do this. In fact, in plotting χ^2 it is not necessarily desirable as will be seen after considering Table I.

Table I

Selected χ^2 Probabilities

Degrees of Freedom	$\bar{\chi}^2 + 3\sigma_{\chi^2}$	$P(\chi^2 > \bar{\chi}^2 + 3\sigma_{\chi^2})$	χ^2 for $P \leq 0.0027$
1	5.24	0.023	9.0
2	8.00	0.018	11.8
3	10.35	0.015	14.2
4	12.49	0.013	16.3
5	14.49	0.012	18.4
6	16.39	0.011	20.2
7	18.23	0.011	21.9
8	20.00	0.010	23.6
9	21.73	0.010	25.0
10	23.42	0.009	26.8

Column three of Table I gives the probability of obtaining a value of χ^2 larger than $\bar{\chi}^2 + 3\sigma_{\chi^2}$, and column four gives the value of χ^2 which is not expected to be exceeded more than 2.7 times in a thousand. The values in the last two columns were read from a graph appearing in Vol. 40, No. 231, p. 376 of the *JOURNAL OF THE AMERICAN STATISTICAL ASSOCIATION* (article by James F. Crow). It would be usual in control work to use as a top limit the value of χ^2 associated with $P = 0.0027$, since the probability of exceeding 3σ in a normal distribution is 0.0027.

The distribution of χ^2 is dependent only on the number of degrees of freedom; consequently neither the center line nor the control limits need be changed when the sample size changes provided that the number of classes is held constant. It should be pointed out, however, that as the sample size increases the *sensitivity* of the χ^2 chart increases. This means that smaller discrepancies in the *relative frequencies* will lead to larger values of χ^2 and small departures from perfect control will therefore be detected more readily. For minimum confusion in interpretation it is therefore advisable to try to maintain at least approximately constant sample size.

Since the individual divergences are squared, χ^2 does not indicate

whether or not quality improves or deteriorates when it gets larger. If it gets larger, it does indicate that the divergence from standard has become larger in some class in some direction. A run of low values of χ^2 would indicate unusually close agreement with the standard.

In the derivation of the distribution of χ^2, Stirling's formula is used in approximating a factorial number which involves the expected class frequency. This approximation is not very good when the class frequency is less than five. So in dividing the distribution to be studied, one should take care to make the class intervals of such a size that none will be expected to contain less than five individuals.

In the case of calculating χ^2 for control chart purpose the number of degrees of freedom will always be one less than the number of classes, because the standard frequencies and the observed frequencies are only forced to agree in their totals.

Examples of Chi-Square Charting

Sometimes yarn is wound into a package form somewhat like a cone. The thing that it is wound onto is a paper tube shaped like an ice cream cone, only open at both ends. Usually it is desired to put more yarn onto the cone than is available on one supply package. For example, the finished cone may weigh four pounds (net) and the supply package may weigh 0.92 pound (net). If this is the case, then on the average 4.35 knots will have to be tied in the yarn on the cone in order to join the yarn from the supply packages. Also, the yarn may break in winding. If this happens additional knots must be tied. For technical reasons all of these knots are placed on the top of the cone by the winding operator. A count of the knots serves as a check on the quality of the yarn. It is obvious that the resulting distribution of cones with various numbers of knots could not be expected to be either binomial or poissonian. But one way of charting the results of such an inspection is to use a χ^2 chart. Table II gives hypothetical data of the kind which might be experienced.

If these relative frequencies are taken to be a good description of the process, then a χ^2 chart, the points of which are computed from subsequent data, will indicate the degree of divergence from this standard. If it is decided that at each inspection about 150 cones should be counted for knots, then the distribution should be grouped into 4 classes as shown in Table III. Then the center line will be $\bar{\chi}^2 = 3$, and the UCL will be 14.2. Table III shows the calculation of χ^2 for one inspection.

Table II

Frequency Distribution of Cones with Various Numbers of Knots

No. of Knots	Frequency No. of Cones	Relative
4	330	0.4125
5	327	0.4088
6	114	0.1425
7	26	0.0325
8	2	0.0025
9	1	0.0012
Total	800	1.0000

Table III

Data and Calculations for χ^2 Chart of Cone Knot Count

No. of Knots	Actual Frequency of Cones c		Expected Frequency of Cones $\bar{c}$		Divergence $\frac{(c-\bar{c})^2}{\bar{c}}$
4	60		59.0		0.02
5	51		58.5		0.96
6	20		20.4		0.01
7	6		4.6		
8	1		0.4		
9	3	12	0.1	5.1	9.34
10					
11	2				
Total	143		143.0		$\chi^2 = 10.33$

Chi-square for subsequent tests would be computed in the same manner.

Fabric is often inspected and graded into three classifications, say A, B, and C. It is possible to construct three p-charts, one for each of the three grades, but one χ^2 chart can be constructed which will serve essentially the same purpose. Suppose that from past experience it has been found that fabric falls into these three grades with the following relative frequencies: A, 94.3%; B, 3.5%; and C, 2.2%. Table IV illustrates how χ^2 is calculated.

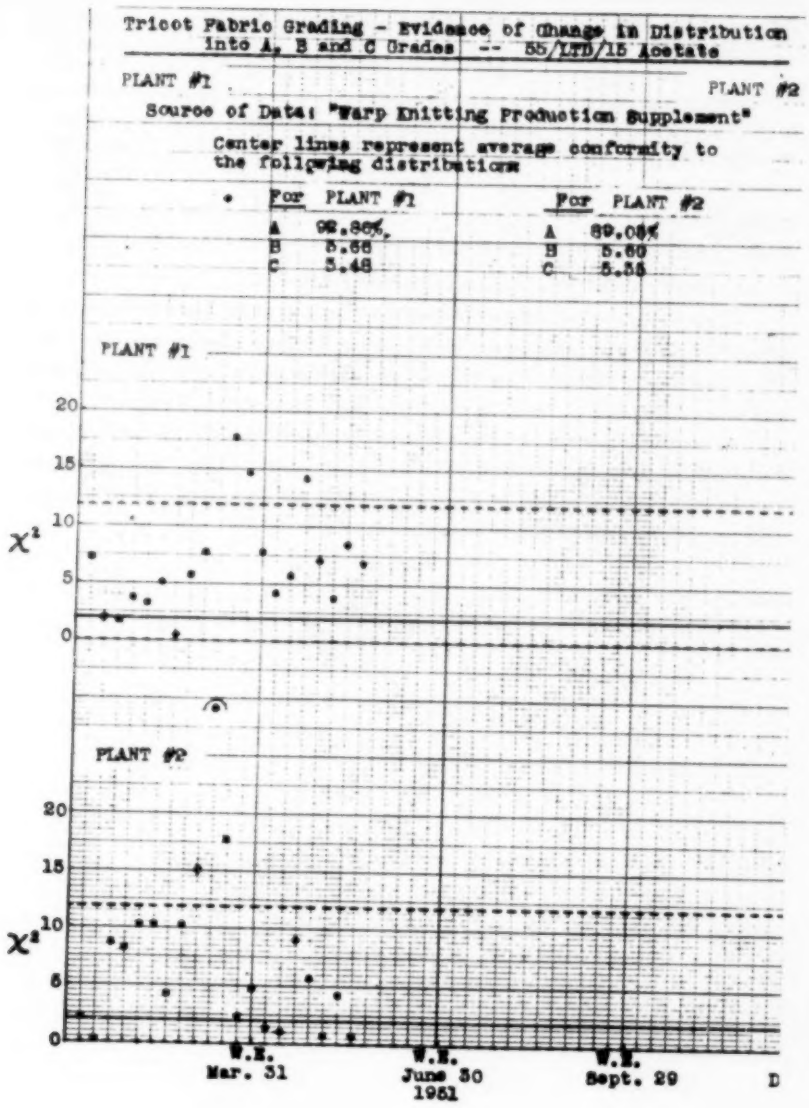

Tricot Fabric Grading - Evidence of Change in Distribution into A, B and C Grades -- 55/LTD/15 Acetate
PLANT #1
PLANT #2
Source of Data: "Warp Knitting Production Supplement"
Center lines represent average conformity to the following distributions
For PLANT #1
A 92.86%
B 5.66
C 5.48
For PLANT #2
A 89.08%
B 5.80
C 5.35
PLANT #1
PLANT #2
χ^2
20
15
10
5
0
W.E. Mar. 31
W.E. June 30 1951
W.E. Sept. 29
D

FIGURE 1

Table IV

Data and Calculations for χ^2 Chart of Fabric Grading

Fabric Grade	Actual No. of Pieces of Fabric c	Expected No. of Pieces of Fabric $\bar{c}$	Divergence $\frac{(c - \bar{c})^2}{\bar{c}}$
A	198	215.9	1.48
B	18	8.0	12.50
C	13	5.0	12.80
Total	229	228.9	$\chi^2 = 26.78$

In this case $\bar{\chi}^2 = 2$, UCL = 11.8, and LCL = 0.

Figure 1 is a χ^2 chart of actual production data. Here χ^2 charts are plotted for the same kind of yarn from two different plants converted into the same style fabric. This illustrates how such a chart might look in actual practice.

A striking aspect of these charts is that they exhibit considerable parallelism. As might be expected, this was due in a large measure to unofficial changes in fabric grading standards, a fault at the knitting plant and not of the yarn plants.

STATISTICAL SAMPLING AND TESTING OF LOTS OR RAW WOOL

Robert G. Levitch and Robert R. Jones
Bigelow Sanford Carpet Company, Inc.

The processing of wool from the raw fiber to the finished yarn or cloth has so many opportunities for applying statistical Quality Control principles that proper treatment of the subject would be too lengthy for one paper. Consequently only the very first step is presented here and that is, of course, the sampling and testing of raw wool. A series covering the full gamut of wool processing is planned and all persons willing to contribute to that program are requested to contact the editor of this supplement. –D.S. HAMBY

For years the testing and appraising of lots of raw wool for physical characteristics were conducted on a rather haphazard basis. This condition resulted not from any lack of desire to do better but rather because the technology necessary for accurate laboratory evaluation had not advanced to the point where a representative sample could be taken. In short, the entire field of raw wool testing centered around and was delayed by the problem of sampling. Well known sampling techniques in use in other industrial fields of control and inspection could not be applied to wool. The very nature of raw wool, the high variability both within and between bales, the diverse baling or packaging practices of different countries, the condition of the wool at the time of baling, and the numerous trade practices in regard to buying and selling, all combined to make the sampling of wool of primary importance and at the same time of utmost difficulty.

Because the Tariff Act imposes a specific rate of duty on the "clean content" of certain classes of imported wool, the Government was directly concerned with the sampling and testing of wool. In the late 1930's, the Bureau of Customs developed the sampling technique known as core boring, as well as suitable procedures for testing such samples. The importance of this development can be appreciated when it is recognized that for the first time a method became available for accurately sampling the bulk commodity wool, valued to industry at many millions of dollars a year. If the technique of mill wool scour testing is reviewed, it is readily understood why a manufacturing organization such as Bigelow-Sanford was enthusiastic about the potentialities of this sampling plan and desired to have it adopted by the Carpet Industry. Mill tests for "yield" had long been recognized as an unsatisfactory test method. Results obtained were erratic, unreliable, non-reproducible, and expensive. The first three characteristics mentioned can be attributed to the fact that the sample bales (the general practice was to scour five per cent of the bales in a lot) frequently were not adequately representative of the lot. In addition, precise control of the condition of the scoured wool was not feasible under mill operating conditions. Accordingly, yields obtained

by such a procedure were viewed with suspicion and reservation. Also, the use of mill production equipment to accomplish this type of test was expensive and time-consuming so that all too frequently it was expedient to omit testing altogether.

Through the kind and generous assistance of Mr. Louis Tanner, Chief Chemist, U.S. Customs Laboratory, and Mr. Herbert Woolner, President, American Conditioning House, core boring of carpet wool and the testing of the samples so obtained were introduced into Bigelow and the Carpet Industry, and the benefits derived have adequately proved the merits of the method.

Since core boring has given the entire wool industry a technique for obtaining a representative wool sample, it is possible to determine lot characteristics important from an economic as well as a production standpoint. The accurate determination of "clean wool content" (quantity of wool substance present in a lot adjusted to standard percentage contents of ash, extractable matter, and moisture) has placed the selling and purchasing of wool on a sound basis. In addition, the determination of this lot characteristic has made the batching or blending of wools more accurate and this, in turn, has made possible an increase in uniformity of production and control of quality.

Before the introduction of core boring, a wool processing plant had to depend, to a large extent, upon the knowledge and experience of the mill men to judge the physical characteristics of wool delivered. Of necessity, yield, color, vegetable matter and burr content, lime content, fiber strength and length, and fiber impurities were all appraised by visual examination. Since these examinations were, for the most part, made by viewing the outside of the bales or by inspecting hand drawn samples, it was only because of the skill and experience of the wool inspectors that the characteristics of the wool involved were even approximately correctly estimated. Core boring has given the industry a method for properly sampling wool bales so that the average characteristics of the entire bale, not merely of the outside portion, can be evaluated. It should be emphasized, however, that the laboratory sampling and testing techniques do not eliminate the need for visual examination of wool lots by competent, practical mill personnel, and at a Company such as Bigelow-Sanford the the combination of theoretical and experimental data with practical experience has proven most beneficial.

Core boring of wool is accomplished by utilizing a specially designed cylindrical tube, one end of which contains a circular cutting edge or blade, the other end being attached to a high speed electric drill. Individual cores of wool are obtained from a bale or package by means of this

tool and the accumulation of a predetermined number of cores constitutes the sample. During coring, attention must be given to such factors as location of coring a bale, depth of penetration, type of wool being sampled, and protection of the drawn sample from outside influences. (Reference is made to A.S.T.M. method D–584 for details of the testing techniques used for determining "clean wool content".)

The major problem in utilizing the core boring technique as applied to carpet wools was the establishment of the proper sampling schedules, that is, the number of cores required and the distribution of these cores throughout a lot. The sampling schedule is affected primarily by certain statistical measures concerned with variability, in which respect the several wool types differ from each other. These measures have not, as yet, been completely determined for all wools. However, a task group of A.S.T.M. Committee D–13, A–3, Section 1, has been collecting necessary data for some time and considerable progress has been made. Because of changing practices among wool suppliers and packers, this work will undoubtedly have to be of a continuing nature, so that current measures of variability may be available.

STATISTICAL ASPECTS

Since the wool within each bale varies from one portion (core) to another and from one bale to another in the same lot, the problem of sampling is to take account of these sources of variation. This is accomplished by taking the statistically proper number of cores from the proper number of bales in each lot of wool that is tested. The proper numbers of cores and bales depend upon several factors: (1)the degree of variability within and between bales; (2) the degree of precision required; and (3) the relative costs of handling a bale and of taking a core. Statistical techniques such as analysis of variance have been employed very successfully in establishing sound sampling schedules that should produce, most economically, samples having the desired precision. A brief description of these techniques follows.

As stated above, the average percentage of clean wool in the bales differs from bale to bale. This variation could possibly be due to the chance effects of the inherent variability of the wool from portion to portion within a bale, or it might be due to some other system of causes. It is necessary to know whether one or two sources of variation exist ("within bale" and "between bale" variances) and their magnitudes. This information can be obtained by the statistical technique known as analysis of variance when applied to the data collected in certain systematic ways. For purposes of illustration, an example is worked through using the following table of yield measurements of five individual cores from each of three randomly selected bales in a lot of Cordova wool. To

facilitate the arithmetic, a constant has been subtracted from each entry In Table 1; this does not affect the results of the statistical analysis.

Table I

Coded Percentage of Yield of Individual Cores
Cordova Wool – Lot 76

Core Number	Bale Number 1	2	3	
1	9	2	8	
2	12	8	6	
3	10	6	9	
4	13	4	9	
5	12	3	16	
Total	56	23	48	127
Average	11.2	4.6	9.6	8.47

The computations required are as follows:

(1) Sum of squares of individual entries $= \Sigma X^2 = 1285$;

(2) Sum of squares of column totals divided by number of entries per column $= \frac{\Sigma C^2}{n_c} = \frac{5969}{5} = 1193.80$;

(3) Square of grand total divided by total number of cores $= \frac{\Sigma T^2}{N} = \frac{16129}{15} = 1075.27$.

Table II

Analysis of Variance of Data in Table I

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	Estimate of
Between bales	(2)-(3) = 118.53	2	59.27	$\sigma_w^2 + 5\sigma_b^2$
Within bales	(1)-(2) = 91.20	12	7.60	σ_w^2
Total	(1)-(3) = 209.73	14		

On the question as to whether the variation between the bales is due to causes other than the variability within bales, the statistical test known as the F-ratio is used, as follows:

$$F = \frac{\text{Mean square between}}{\text{Mean square within}} = \frac{59.27}{7.60} = 7.79.$$

From tables of the critical values of F it is found that such a high value in this case is very unlikely unless other causes of variations do actually exist between bales. It is concluded, therefore, that the two suspected sources of variation do exist and must be taken into account.

From the mean squares in Table II, estimates of the within-bale variance, σ_w^2, and the between-bale variance, σ_b^2, may be obtained. These are 7.60 for σ_w^2 and (59.27 - 7.60) ÷ 5, or 10.33, for σ_b^2.

After the two variances have been reliably established from data such as the above on an adequate number of lots of each type of wool, it is necessary to decide how accurate a sample is required for the purpose at hand. It must be remembered that increase in accuracy is obtainable only at increased cost; for economy, the maximum possible tolerances that are satisfactory should be established. For carpet wool, general practice has been to require that not more often than once in 20 should a sample differ from the true average of the lot by more than 1% clean wool content. In statistical terms, this requirement is met by setting the allowable error, E, equal to 1% and the probability factor, t, equal to 1.96 in Equation 1, below.

The relationship between the number of bales to be sampled, n, and the number of cores to be taken from each sampled bale, K, is given by:

$$n = \frac{N(\sigma_w^2 + K\sigma_b^2)}{KN(\frac{E}{t})^2 + K\sigma_b^2} \qquad (1)$$

where: n = number of packages to be cored
N = number of packages in lot
K = number of cores to be taken from each sampled package
E = sampling error, in percentage
t = probability factor
σ_w^2 = within-bale variance
σ_b^2 = between-bale variance.

The number of cores per bale, K, may be selected arbitrarily and the corresponding number of bales to be sampled can then be calculated from Equation 1. Obviously, a whole series of sampling plans, with different pairs of values for n and K, is possible, and all will produce samples of the same precision. The plans may not, however, be equally economical. For example, if it is necessary to do considerable expensive work to draw bales from storage in order to core them, it would be better to increase the number of cores per bale and to decrease correspondingly the number of bales handled. The most economical number of cores per bale can be calculated by Equation 2:

$$K = \frac{\sigma_w}{\sigma_b}\sqrt{\frac{C_1}{C_2}} \qquad (2)$$

where: K = most economical number of cores per bale
C_1 = cost of handling a bale for sampling
C_2 = cost of taking one core.

As an illustration, we will use the above formulas and the variances calculated from Table I to set up a proper sampling plan for Cordova wool

(assuming that sufficient data were presented on lot 76) for the following conditions:

1. Cost of handling a bale	$1.00
2. Cost of taking a core	$0.25
3. Desired accuracy	±1%
4. Risk of not achieving desired accuracy	0.05
5. Lot size	100 bales

Number of cores per bale

$$K = \frac{\sigma_w}{\sigma_b}\sqrt{\frac{C_1}{C_2}} = \sqrt{\frac{7.60}{10.33}} \times \sqrt{\frac{1.00}{0.24}} = 1.72.$$

Set K at 2 cores per bale.

Number of bales to be cored

$$n = \frac{N(\sigma_w^2 + K\sigma_b^2)}{KN(\frac{E}{t})^2 + K\sigma_b^2}$$

$$= \frac{100(7.60 + 2\times 10.33)}{2\times 100(\frac{1}{1.96})^2 + 2\times 10.33} = 38.89.$$

Set n at 39 bales.

Hence, the best core sampling plan for lots of 100 bales of Cordova wool under the conditions described would require that two cores be taken from each of 39 bales selected at random.

Further details of sampling plans are given in A.S.T.M. Method D1060–49T, which gives solutions of Equation 1 for various combinations of the two variances, for a number of different lot sizes and values of K.

It is interesting to note that this same problem of sampling within and among units of product applies to commodities other than wool and it is for this reason that the statistical presentation has been relatively detailed. Cotton, rayon fiber, yarns, chemicals and many other products used in the textile industry will readily fit into this pattern of sampling.

The authors gratefully acknowledge the generous counsel and suggestions offered by Mr. Louis Tanner, Chief Chemist, U.S. Customs Laboratory in connection with the preparation of this paper.

References: (1) A.S.T.M. Standards on Textile Materials Method D–1060–49T, American Society for Testing Material, Philadelphia, Pennsylvania.

(2) Brownlee, K.A., "Industrial Experimentation", Chemical Publishing Co., Inc., Brooklyn, N.Y.

(3) Tanner, L. and Deming, W.E., "Some Problems in the Sampling of Bulk Materials", Proceeding of A.S.T.M., Volume 49, pp. 1181–1186 (1949).

QUALITY CONTROL IN THE MANUFACTURE OF CELLULOSE ACETATE YARN

F. J. Fitzgerald

Technical Control Superintendent, Celco Plant, Celanese Corp. of America

Acetate is "the beauty fiber"—and beauty is as beauty does! A well planned, thorough and integrated program for control of quality is an essential part of the reputation acetate has built for fine fabrics.

Acetate belongs properly in the company of chemical fibers; that is, it is not simply regenerated but is the result of spinning a polymer made by chemical combination. The basic ingredients are a highly purified form of cellulose, obtained principally from cotton linters or wood, and acetic anhydride. These combine to form cellulose acetate, which is soluble in certain organic solvents. By dissolving the cellulose acetate, extruding the solution through tiny holes, and then evaporating the solvent from the thread so formed, the familiar acetate yarns are produced. Like other chemical yarns, these absorb relatively little moisture and are strong when wet.

Early in its life the Celanese Corporation of America found that it had to control some weaving and finishing facilities in order to promote, by example, the use of its products. The idea of integration was thus born, and it has been natural for an operation which is as much chemical as it is textile to wish to control its sources of chemical raw materials as well. At least part of all important raw materials is now made within the company, and enough of the product yarn is woven or knit, and dyed and finished, to provide for development and for quality control.

Whatever the reason, this company integration is the backbone of of our quality control. It provides an opportunity for quality evaluation of the product of each step of the manufacturing process, by using it in a typical way in the next step. By proper scheduling it is possible for us to predict exactly how our yarn products will behave for our customers because we have tried them ourselves.

For such a multi-plant operation a decentralized, but closely knit, quality control organization works best. In our corporation the quality function is carried on by the Technical Control Department which is headed by a Vice President in the Central Offices of the company. In each manufacturing plant there is a Technical Control Superintendent who is on the staff of the Plant Manager. At the same time he is closely

connected to all the other Technical Control Superintendents and to the central office through a Co-ordinator of Technical Control.

Quality control is an important function of the Technical Control Department in each plant. Use is made of control charts, of planned experiments, and of all other types of statistical assay. Department personnel are familiar with all the manufacturing methods within their own plant and in the other plants whose products it takes or whose raw material it supplies. They work closely with the heads of production departments to assist them in maintaining the quality for which they are responsible, and to aid in developing improved manufacturing methods. They are in close contact with the Central Research Laboratories, and and with plant control laboratories which provide much of the data which they collect and interpret.

WHAT THE YARN PLANT DOES

Our company is made up of many manufacturing units, some of which produce high-grade cellulose (dissolving pulp) from Canadian trees and Mexican cotton. There are also plants which make acetic acid and acetone from natural gas, and plants like our own at Celco, which combine these to make acetate yarns. There are smaller mills which spin some of the fiber into yarn and which weave these yarns, and continuous filament yarn into greige fabric. Some of the yarns are knit into jersey fabrics and there is a finishing plant capable of dyeing a major portion of the woven and knit fabrics made within the company. Each of these units has its own quality control program which is blended into the overall program of the company.

At Celco, the various raw materials are put together to make a white, flaky powder called C. A. (for cellulose acetate) flake. The flake is then dissolved in acetone, and the resulting "dope" forced through fine holes in spinnerettes to make threads which are dried by warm air currents. When these threads have been combined to form yarns of the proper size they must be twisted and then repackaged in the way in which the trade would like to have them.

Some of the threads are not combined into relatively small yarns, but are, rather, put together by the thousands to form a thick rope called a "tow". This tow may be sold as it is or cut into lengths a few inches long to be baled and sold as staple fiber.

Celco ships yarn as cones, cheeses, tubes, beams, bales, and cartons to consumers throughout the world. A small, but, for quality control, a very important part goes to other Celanese plants.

Statistical control charts used in the yarn plant fall into two categories. Those of the first kind are kept at the process levels; in the laboratories and on the operating floors. Some of these are in loose-leaf books or posted on bulletin boards. For greater emphasis, some are painted on large fiberboard panels, and pins with colored heads are used to plot the points. Chemical fibers are produced by a continuous process, and almost all charting is timewise rather than by unit of production, the charts usually covering a comparatively short time period such as a day, a shift, or an hour. An example showing the control of moisture in staple fiber may be found in Figure I. Another feature of the process control charts, and one which distinguishes them from the second type to be discussed below, is that they generally relate to individual machines or other subdivisions of production, and not to entire items or production lots.

The second kind of control charts might be called "Reports to Management". Early in our experience we found that printed words and columned figures were an inadequate and annoying way to convey ininformation about overall quality to those who needed to know it. We wanted to inform the heads of the production departments within the plant, the plant manager, persons in other plants which are affected, and management in the central offices of the company, and we wanted to do it as effectively as possible. The solution was to distribute the control charts themselves, but in facsimile. Figure II shows how one page of the summary looks.

A carefully selected list of data, adequate to cover important levels of intermediate processing as well as final production, is compiled and computed in the Technical Control Office. These data, when reduced to the proper form, are entered on charts reproduced on transparent film (made, incidentally, of cellulose acetate). The charts are kept up to date, and at intervals sufficient copies are made by a dry-printing process for distribution to all those who need them.

Such charts as these will naturally tend to be summaries, covering an entire product type and a somewhat longer time period than the process charts. The time is usually one week, and the majority of the control charts will be of the average and range type with a sample size of seven, to make convenient use of data provided on a daily schedule. Percent defective plots also find wide use, as do charts of defects, particularly defects per unit.

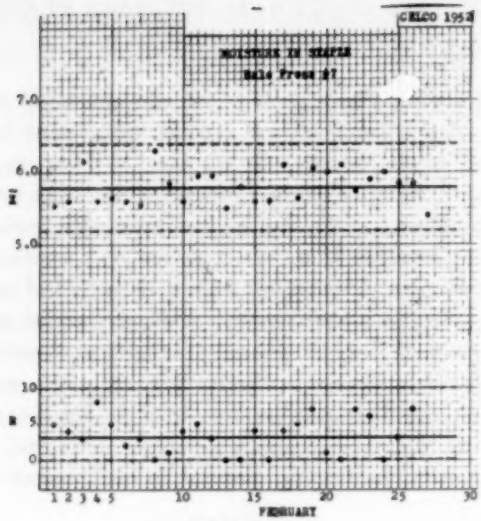


FIGURE 1

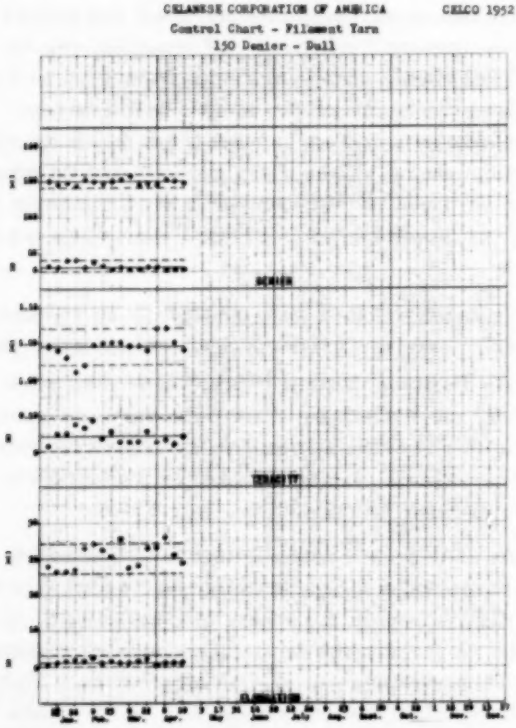


FIGURE 2

The production superintendents are, of course, informed immediately whenever their processes or products show significant trends or are outside control limits. But besides this, the actual control charts, available to them at their own desks, are a graphic reminder of quality and a stimulant to the elimination of trouble spots and to quick investigation of unusually good conditions, with resulting permanent improvement. The task of those who must interpret for top management quality trends in the whole company is made much easier when complete histories of certain variables can be laid out in graphic style on a few sheets of paper. An additional advantage of the facsimile system is that one chart covers a full year, and each time that it is issued it incorporates all the previous data. Thus, it is necessary to keep only the final set of charts for each year and filing is greatly simplified.

An important use of the facsimile chart is in relaying, from a consuming plant within the company, information about the product being supplied it. For example, the Celco plant sends a small portion of its staple fiber to the carding and spinning mill at Lanese. In return it receives control charts which show the quality of the current staple product. In the more general case, however, because quality is controlled, few checks are made of raw materials which originate within the company, except where changes may take place in transit or in storage.

BACKGROUND FOR QUALITY

An essential part of the quality control of any company is in the setting and maintaining of manufacturing standards, whether this is done by the group actually charged with quality control or not. In our company this is also a function of the Technical Control Department, in close cooperation with the production department affected. The control group prepares a standard operating procedure for each distinct manufacturing operation, and these are standardized, wherever possible, among plants performing similar operations.

At the same time we could not survive in a competitive field unless we were continually developing in the direction of better quality and lower costs. The existence of a set of standard procedures, which cannot be varied under ordinary circumstances, requires the co-existence of a strong development program and efficient methods for the evaluation of proposed changes. Control charts, planned experiments, correlation and regression techniques, and tests for significance all have their places in a program aimed at new and improved products and processes, better ways of handling and packaging yarn, and new and better tests for quality.

TRAINING FOR QUALITY

The so-called inauguration of quality control in a company is never that. The company could not have come into existence or continued in existence if it had not had control of its quality. What is actually inaugurated is modern quality control which makes use of new and efficient mathematical and engineering tools, responsibility for the use of which is vested in a group of specialists.

It was recognized quickly in our company that the support of management and the existence of the tools and the specialists was not enough. The old line quality control, which consisted of people and attitudes, must still prevail and be strengthened rather than superseded. This is especially true of the textile industry where we find not only that "quality cannot be inspected in", but that it is very difficult to inspect bad quality out! Quality must be built in, and we have consciously fostered process control and product evaluation (rather than inspection) as being best for our purposes.

But if it was people and their attitudes that we needed on our side, that made it more necessary to train the people and to generate the proper attitudes. To do this, training programs were set up at several levels and a well-known teacher and consultant was engaged to help. Individuals in the various departments, whose direct charge would be quality control, were given a fairly advanced course. The management group, also, was told how it worked and what it should do, but the largest part of the time available was given to instructing the foremen. This was not primarily to teach them to set up and maintain their own control charts, but to elicit their understanding and sympathy for what was being done in their departments and to drive home the emphasis being put on quality from the top down. It is only through persistence and uncompromising insistence that the need for high quality at all times becomes a conscious urge on the part of every worker.

CONCLUSION

Celanese acetate has had the benefit of modern quality control for only a few years. We feel that, as a result, its fine reputation has been maintained and improved in the face of ever more critical standards. That means that the organization and methods which have been described are doing an effective job of controlling quality and improving operations. Production and control work closely together on common problems, while, at the same time, the functioning of the control group as a staff aid to management at all levels within the company keeps it independent and efficient. Strong lines of communication among the manufacturing plants and between the plants and the central office complete the requirements for a successful organization.

ANALYSIS OF VARIANCE APPLIED TO TEXTILE PROCESSES

Edward S. Rudnick
Director of Research, Wamsutta Mills

The following article, reprinted from the October 1948 issue of Textile Research Journal, illustrates specific examples of the Analysis of Variance in the author's organization.

SPECIFIC ANALYSES OF VARIANCE

In presenting examples of the application of analyses of variance to specific operating problems, some familiarity with the principles of statistics on the part of the reader is assumed.

Presented below are the actual steps taken in performing a three-factor analysis of variance. This particular analysis is based on roving weight for specific lengths. The actual results are unimportant as far as this presentation is concerned, since they apply only for the particular conditions under which the tests were made. The object of the presentation is to show the methods by which such analyses are performed and the value of such an analysis. Since the details of each step are given to provide a text of the mechanics of an analysis of variance, one might feel that it is an extremely long and complicated procedure. Actually, once the details are mastered, a three-way analysis such as that presented below is rather simple and can be easily completed in 2 hours once the data have been collected.

Variables Considered

In this case, the three variables considered to be affecting the weight/length of the roving are as follows:

1. Between positions, P: Three positions on each full bobbin were chosen – outside, middle, and inside.
2. Between spindles, S: Four specific spindles, chosen by drawing from random numbers, were used throughout.
3. Between days, D: Four successive days of production were chosen – Wednesday, Thursday, Friday, Monday.

The experiment is designed so that all possible combinations of the three factors occur, $3 \times 4 \times 4$, or 48 separate samplings of output, one for each position-spindle-day combination.

In such an analysis as this, no attempt should be made by the experimenter to alter the normal operating conditions. However, the variables not being investigated should be controlled as much as possible – for example, having the same technician do all the weighing on the same balance, and conditioning all specimens the same length of time. Thus, if no attempt is made to control the main effects, the variables will act in conjunction with each other as they do in actual practice, and any of these interactions which are significant can be determined.

Since we are interested only in variance differences, the actual magnitude of the data is of little importance. Thus, in the Grand Table of Data, decimal points and units (grains) have been omitted. It simplifies the work when using a calculating machine to work with the original data using all positive numbers even though the number of digits used may be greater.

ANALYSIS OF VARIANCE OF ROVING – GRAND TABLE OF DATA

		Postions		
Day	Spindle	Outside	Middle	Inside
Wed.	1	395	398	382
	2	401	396	373
	3	394	394	387
	4	396	406	390
Thurs.	1	402	392	396
	2	408	386	374
	3	373	381	387
	4	384	396	394
Fri.	1	392	392	372
	2	397	383	370
	3	383	408	387
	4	401	370	385
Mon.	1	415	394	393
	2	391	378	384
	3	393	383	400
	4	402	385	397

ΣX = 18,740
ΣX^2 = 7,321,544

Outline of Procedure

At this point, it might help to state briefly what such an analysis as this is trying to do. Using the data which apply to each variable and interaction, the respective variance estimates of the grand population are computed. These are found by computing the "sum of squares" for each

of these sets of data and dividing by the number of degrees of freedom associated with that variable or interaction. The variance estimate is called the "mean square." If none of these individual variables had a significant effect on the process, then these mean squares would all be about the same, with no significant differences. Thus, the effect of each variable is finally ascertained by ordinary variance comparison tests for significance, such as an "F" test. These steps will be more fully clarified in the actual analysis which follows.

Summation Subtables

An actual schedule should be made of the various summations which are required, and these should be numbered. Also, if different-colored pencils are used for reporting the data of the original table (such as all data for Thursday in red, Friday in green, and Monday in blue), it will be simpler. These suggestions may not be necessary in a three-way analysis such as this, but in a four- or five-way analysis, where summing must be done over as many as 30 factors, the advantages are great. Here, to get the individual sums of squares, it is necessary to sum the data over each of the following factors: I. Positions (P); II. Spindles (S); III. Days (D); IV. Positions and Spindles (PS); V. Positions and Days (PD); VI. Spindles and Days (SD).

TABLE I. SUMMATION OVER POSITIONS

	Spindle			
Day	1	2	3	4
Wed.	1175	1170	1175	1192
Thurs.	1190	1168	1141	1174
Fri.	1156	1150	1178	1156
Mon.	1202	1153	1176	1184

ΣX = 18,740
ΣX^2 = 21,953,396

TABLE II. SUMMATION OVER SPINDLES

	Position		
Day	Outside	Middle	Inside
Wed.	1586	1594	1532
Thurs.	1567	1555	1551
Fri.	1573	1553	1514
Mon.	1601	1540	1574

ΣX = 18,740
ΣX^2 = 29,272,892

TABLE III. SUMMATION OVER DAYS

Spindle	Position Outside	Middle	Inside
1	1604	1576	1543
2	1597	1543	1501
3	1543	1566	1561
4	1583	1557	1566

ΣX = 18,740
ΣX^2 = 29,274,120

The first three are then obtained (See Tables I–III) from the Grand Table of Data and it is here that the advantages of multicolored tables are evident.

From Tables I–III the succeeding set of tables (Tables IV–VI) are made. For instance, in order to sum over Positions and Spindles as in Table IV, either Table I can be summed over Spindles or Table II can be summed over Positions, whichever is simpler.

Sums of Squares – Total

The next step consists of computing the sums of the squares of all the data in each of Tables I–VI and in the Grand Table of Data. The actual sums of the individuals, which are obtained simultaneously with the sums of the squares on a calculating machine, should of course be the same throughout. These results have been recorded at the lower right in each of the tables. (On the originals these figures are in a different color for emphasis.)

A so-called "correction factor" is then computed from the sum of all the individuals; this is:

$$\text{C.F.} = \frac{(\Sigma X)^2}{N} = \frac{(18,740)^2}{48} = 7,316,408.$$

The actual "sums of squares" are computed for each variable. The "total sum of squares" is merely the sum of the squares of each variate of the Grand Table, less the "correction factor" (see column 2):

TABLE IV. SUMMATION OVER POSITIONS AND SPINDLES

Day Wed.	Thurs.	Fri.	Mon.
4712	4673	4640	4715

ΣX = 18,740
ΣX^2 = 87,800,698

TABLE V. SUMMATION OVER POSITIONS AND DAYS

Spindle				
1	2	3	4	
4723	4673	4640	4715	ΣX = 18,740
				ΣX^2 = 87,800,946

TABLE VI. SUMMATION OVER SPINDLES AND DAYS

Position			
Outside	Middle	Inside	
6327	6242	6171	ΣX = 18,740
			ΣX^2 = 117,074,734

Total sum of squares = ΣX^2 - C.F.
= 7,321,544 - 7,316,408
= 5,136.

Sums of Squares— Primaries

The actual "sums of squares" for each of the primary variables is then found by taking the sum of the squares computed in Tables IV-VI for each of the respective variables, dividing this by the number of individuals originally making up each component of the variable, and subtracting the "correction factor," as shown below:

"Among Positions" Sum of Squares (from Table VI):

$$P = \frac{117,074,734}{16^*} - 7,316,408 = 763.$$

"Among Spindles" Sum of Squares (from Table V):

$$S = \frac{87,800,946}{12} - 7,316,408 = 338.$$

"Among Days" Sum of Squares (from Table IV):

$$D = \frac{87,800,698}{12} - 7,316,408 = 317.$$

Sums of Squares — Interactions

The interaction sums of squares are found similarly, except that in this case not only must the correction factor be subtracted but also the primary sums of squares of which the interaction consists.

* *Actually, the denominator is more readily determined by dividing the total number of individuals, 48, by the number of parts to the variable under question — 3 positions in this case.*

"Among Positions and Spindles":

Subtraction term = C.F. + P + S
= 7,316,408 + 763 + 338
= 7,317,509;

$$PS = \frac{29,274,120\dagger}{4} - 7,317,509 = 1,021.$$

"Among Positions and Days":

Subtraction term = C.F. + P + D = 7,317,488;

$$PD = \frac{29,272,982\ddagger}{4} - 7,317,488 = 758.$$

"Among Spindles and Days":

Subtraction term = C.F. + S + D = 7,317,063;

$$SD = \frac{21,953,396*}{3} - 7,317,063 = 736.$$

Mean Squares

These results are summarized (in the Summary Table) together with the respective variance components and degrees of freedom for determination of the mean squares (variance estimates). The degrees of freedom are the number of independent variates summed to form the total sum of squares for the variable less the number of constants based on those variates. For each of the three primary variables, there is one constant – the mean – based on its variates, so that the degrees of freedom for each is the number of components making up the variable less one. In other words, if we knew the mean value for the spindles, we would have to know three other individual spindle values in order to ascertain the fourth. The interaction degrees of freedom are simply the products of the individual degrees of freedom making up the specific interaction.

In the Summary Table, "V" indicates a variance or standard deviation squared. The actual coefficients of these variance terms have not been included. It can be seen that the sums of squares, when computed in the above manner, are actually variances multiplied by n, the number of degrees of freedom. Therefore, all the mean squares, or actual variance estimates of the grand population, are determined by dividing each sum of squares by its respective degrees of freedom.

†*The numerator is the sum of the squares given in Table III, while the denominator is the number of factors from the Grand Table of Data which go to make up each factor in Table III.*

‡*From Table II.* ** From Table I.*

The residual variation is that variation which cannot be accounted for by the primary variables or their interactions. It is the inherent experimental error. Its variance estimate is best found by subtracting the sums of all the sums of squares and degrees of freedom from the respective totals just found and dividing the residual sum of squares by the residual degrees of freedom.

Interaction Variance Comparisons

Now the necessary variance comparisons of the mean squares can be made to determine which variables have a significant influence on the process being investigated. A definite system must be adopted for this and can be ascertained here by following the actual steps of the comparison.

SUMMARY TABLE

Source of variance	Components	Sum of squares	D.F.	Mean square
P	$V_O+V_{PS}+V_{PD}+V_P$	763	2	382
S	$V_O+V_{PS}+V_{SD}+V_S$	338	3	113
D	$V_O+V_{PD}+V_{SD}+V_D$	317	3	106
PS	V_O+V_{PS}	1021	6	170
PD	V_O+V_{PD}	758	6	126
SD	V_O+V_{SD}	736	9	82
Residual	V_O	1203	18	67
Total		5136	47	

It is assumed that the residual mean square is the best estimate of the population variance. Any mean square which is significantly greater than this value indicates that the variance components in question are real – have a real effect.

The interaction mean squares are first compared, starting with the smallest value. If any of these mean squares are smaller than that of the residual mean square, then their components are considered to be unreal and can be immediately lumped with the residual variance. In the present case all of the mean squares are greater than the residual mean square; so the SD interaction mean square, the smallest is compared first. Using ordinary variance comparison tests–that is, the "F" test with Snedecor's Tables– this mean square is compared with the residual mean square as follows:

$$F = \frac{82}{67}\begin{matrix}(9\text{ D.F.})\\(18\text{ D.F.})\end{matrix} = 1.22, \text{ which} < F_{.05} \text{ of } 2.46,$$

where D.F. = degrees of freedom.

Thus this interaction cannot be shown to have a significant effect on the process (based on the 5% significant level); the V_{SD} component is not real and can be considered as part of the residual variance, V_O. It is therefore, lumped with the latter in order to obtain a better estimate of the residual variance with more degrees of freedom:

Source of variance	Sum of squares	D.F.	Mean square
Residual	1203	18	
SD	736	9	
	1939	27	71.8 (new residual)

The interaction component V_{SD} may be crossed out wherever it appears in the above table, since it is now part of V_O.

The PD interaction mean square, which is the next smallest, is now compared with the new residual mean square.

$$F = \frac{126}{71.8} \begin{matrix} (6 \text{ D.F.}) \\ (27 \text{ D.F.}) \end{matrix} = 1.75, \text{ which} < F_{.05} \text{ of } 2.46.$$

As with the previous interaction, this one cannot be shown to be significant; the variance component can be deleted from the Summary Table and effectively lumped with the residual variance, V_O.

Source of variance	Sum of squares	D.F.	Mean square
Residual	1939	27	
PD	758	6	
	2697	33	81.5 (new residual)

The last interaction, PS, is next compared:

$$F = \frac{170}{81.5} \begin{matrix} (6 \text{ D.F.}) \\ (33 \text{ D.F.}) \end{matrix} = 2.08, \text{ which} < F_{.05} \text{ of } 2.39.$$

Again, this interaction is not significant at the 5% level and the component V_{PS} can also be lumped with the residual variance.

Source of variance	Sum of squares	D.F.	Mean square
Residual	2697	33	
PS	1021	6	
	3718	39	95.3 (new residual)

In this investigation, none of the interactions turned out to be significant. However, if one or more had been, this would most likely have been due to a cause-and-effect relationship between the variables involved.

Primary Variance Comparisons

The primary mean squares are next compared. Since none of the interaction variance components are real, the significance of the primary variance components can be determined by a direct comparison of the respective mean squares with the residual mean square. Had any of these interactions been significant, the mean square of the primary variable containing this significant component would have to be compared with the interaction mean square instead of that of the residual in order to determine the significance of the component not contained in the interaction.

Commencing again with the smallest mean square value, D, the following comparison is made:

$$F = \frac{106}{95.3} \begin{matrix} (3\ \text{D.F.}) \\ (39\ \text{D.F.}) \end{matrix} = 1.11, \text{ which} < F_{.05} \text{ of } 2.84.$$

Since the effect of the "between days" variable cannot be shown to be significant, its variance estimate is lumped with that of the residual:

Source of variance	Sum of squares	D.F.	Mean squares
Residual	3718	39	
D	317	3	
	4035	42	96.0 (new residual)

Next, the S mean square is compared:

$$F = \frac{113}{96.0} \begin{matrix} (3\ \text{D.F.}) \\ (42\ \text{D.F.}) \end{matrix} = 1.17, \text{ which} < F_{.05} \text{ of } 2.83.$$

Thus, the "between spindles" variable is not significant at the 5% level either and its variance estimate can be lumped with that of the residual:

Source of variance	Sum of squares	D.F.	Mean Square
Residual	4035	42	
S	338	3	
	4373	45	97.2 (new residual)

The last item is P, the mean square of which is compared as follows:

$$F = \frac{382}{97.2} \begin{matrix} (2\ \text{D.F.}) \\ (45\ \text{D.F.}) \end{matrix} = 3.93, \text{ which} > F_{.05} \text{ of } 3.20.$$

Therefore, the V_P variance component is significant, if the 5% significance level is accepted. We can say, with less than a 5% possibility of being wrong, that the "between positions" variable in the present case has a significant effect on the process.

Three-Factor Analysis—Conclusions

If none of the variables had turned out to be significantly different from the residual, this would indicate that the inherent experimental error was greater than the effect of any of the variables being considered.

When this analysis was started, it was suspected that any one or a combination of the three variables considered—days, spindles, or positions on the bobbins—might have a significant effect on the product of of this roving frame. A study of the data still did not give the solution. But the general analysis of variance did show something of importance—*i.e.*, that the only variable having a significant effect on this process was the "between positions" variable. This indicated that this roving frame was probably out of control as far as its building mechanism was concerned, giving a greater draft in the inside of the bobbin than on the outside.

If this difficulty could be corrected, another analysis could be made in order to determine whether or not the other variables would then be significant. However, as is often the case if nothing can be done about the error, the knowledge of the error should be taken into account in future sampling. Thus, in testing the product of this roving frame, only full bobbins should be used to compare the roving of different specimens. However, from the other conclusions, it would not matter which spindles or which days were chosen.

In a similar analysis on a spinning frame, the variation between spindles was significant and that between positions was not. Comparing the results of these two analyses, the differences can be accounted for by the facts that the spindles of the roving frame were each gear-driven whereas those of the spinning frame were tape-driven, and that the roving frame had a differential builder mechanism while the spinning frame did not. Each general analysis reveals its own points of value, some of great economic importance and others of consequence with respect to quality.

Theoretically, there is no limit to the number of variables which can simultaneously be taken into account. The author has made several such analyses using 4 factors and two using 5 factors in investigations of yarn strength. In the latter instances the variables considered were: (1) between positions on the bobbin, (2) between bobbins from the same spindle, (3) between spindles, (4) between spinning frames, and (5) between days of the week. However, when this number of variables was considered, it was necessary to replicate over one of the variables —breaking the experiment down into separate four-factor analyses—to ascertain the significance of some of the primary variables. The only advantage of taking this number of variables into account is to investigate all possible interactions, but most of the higher order interactions are incapable of explanation even when significant.

Thus, the author would recommend 2 or 3 simple three-factor analyses rather than one five-factor analysis.

The advantages of small general analyses of variance can never be overestimated. These analyses are extremely useful tools which give answers to a variety of questions in the textile industry incapable of solution by any other means.

STATISTICAL QUALITY CONTROL IN THE TEXTILE MILL

Norbert L. Enrick

P.O.M. CO. – INDUSTRIAL CONSULTANTS
WERNER TEXTILE CONSULTANTS

Little has been written in this Journal on statistical applications to control of quality in textiles. Yet, this field has many applications from which many readers may draw interesting parallels to their particular fields. To mention but one, we find in the drawing process in textiles, a physical replica of the statistical formulas originally developed for explanation of sampling theory. This, and other applications, are elaborated below.

While articles on the new science of statistics in the textile field abound, they generally appear in textile journals and are replete with technological matters and terms which are of no concern to the general reader. In the following, therefore, an attempt is made to present some of the most interesting highlights of textile applications free from any complex or unexplained textile terms.

Although many of the data persented are stated in general terms, they are based usually on a large number of actual observations accumulated by the writer in more than a score of mills in the U.S. and Canada.

The statistical tools most widely applied are four:

Fiber Test Correlation – Raw fiber tests of strength, uniformity and fineness are correlated with expected yarn and cloth strength, yarn uniformity and running performance. Especially in cotton, such statistical correlation studies are suitable for aiding the buyer in purchasing the most desirable cotton for a particular use.

Analysis of Variance – Determining the within-machine and among-machine variations from process to process, and thereby isolating any processes where excessive variations are introduced. The mixing, doubling and drafting of stock which occurs from process to process can be evaluated mathematically as to its effect in increasing or reducing expected variations.

Control Charts – Conventional average and range charts for control of weights, moisture, waste, sizing and various other physical and chemical requirements.

Sampling Plans – Inspection of those items in a textile mill that fall in the "go-nogo" classification, such as gauge check of bobbin or cone diameter and recheck inspection of cloth. Sequential sampling has been

used to advantage for this purpose.

This paper will be principally concerned with the statistical analysis of variations, from process to process, so as to manufacture a uniform end product. The particular example is taken from the spinning of cotton yarn, beginning with the raw cotton, the basic processing of which is presented in Figure 1.

CONTROL OF VARIATIONS

A birdseye view of the variations problem can be gained by examining and testing a spinning bobbin. Assume that this bobbin has been spun to a yarn number of 20. This means that each 840 yards of this yarn should weigh 1/20 pound. To verify this, it is customary to reel a skein of 120 yards and weigh it on a scale giving direct readings in Yarn Number.

If we make several such determinations from the same bobbin, we might find that the standard deviation of skein weights is .4, for example. We will find a greater variation between skeins of different bobbins from the same frame, and even greater variations if the bobbins come from different frames.

Normally, variations are directly proportional to the weight per unit length of yarn produced on similar equipment. It is customary, therefore, to bring the standard deviation of different yarn numbers upon a common denominator by expressing it in terms of Coefficient of Variation. Thus, a number 10 yarn with a standard deviation of 0.4 is comparable to a number 50 yarn with a standard deviation of 2.0, both yarns having the same coefficient of variation of 4% (0.4/10 and 2.0/50 respectively). This relationship generally holds true also for comparison of process to process variations, once proper allowances have been made for the effect of doublings and drafting as well as unit length of stock weighed.

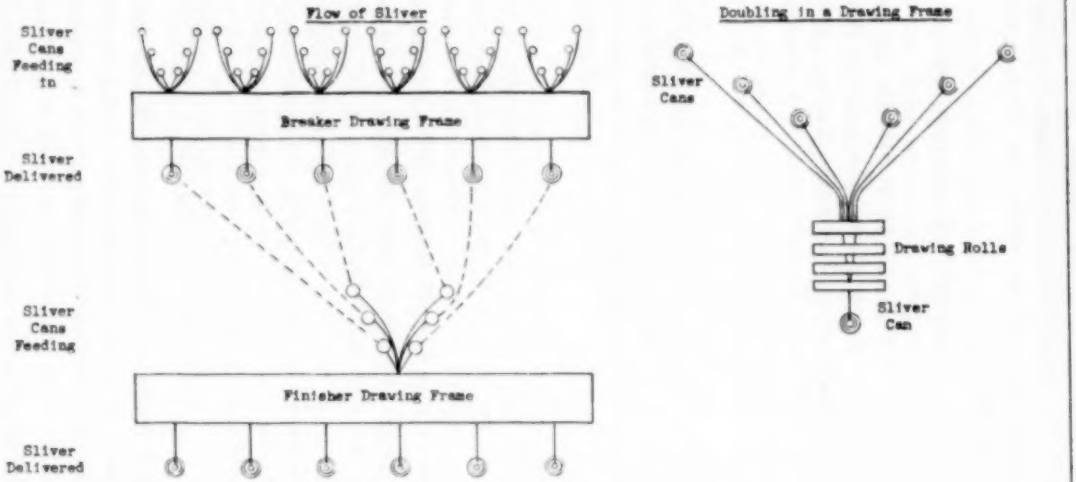
PROCESS TO PROCESS VARIATIONS

Figure I illustrates a typical process, breaker and finisher drawing, in which doubling occurs. Cans of sliver coming from the preceding carding operation, are placed at random at the feed section of breaker drawing. Thereafter, the sliver delivered at the front of the breaker is fed into the finisher. In each instance, six slivers are fed and doubled into one strand at the delivery end of the frame. This process occurs first in breaker drawing and is repeated in finisher drawing, thus giving a total doubling of 6 x 6, or 36.

A drawing frame is generally set up in such a manner as to exert sufficient "draft" or attenuation upon the sliver fed, so that the single

FIGURE 1

FIGURE 1: BREAKER AND FINISHER DRAWING



Note: For simplicity, only 1 of the 6 feed sections shown on finisher drawing.

strand of sliver delivered is equal in unit weight to the six strands fed in back of the delivery.

If variations are measured on the basis of grains per yard of sliver, the question comes up: "By how much should the doubling in drawing reduce variations in the sliver?" Then, by comparing actual variations with expected variations, conclusions can be drawn as to the proper adjustment and setting of the machinery, and, not infrequently, upon the reliability of the personnel engaged in routine testing.

Expected variations must now be calculated mathematically by reference to the well known formula for the standard error of the mean, taken from sampling theory. However, the following quantities and symbols are substituted:

n = number of doublings in the machine
V = coefficient of variation
m (subscript) = within machines
a (subscript) = among machines
o (subscript) = overall
e (subscript) = expected
p (subscript) = previous process

We then have:

$$V_o^2 = V_m^2 + V_a^2$$

and,

$$V_{me} = \frac{V_{op}}{\sqrt{n}}.$$

Now, assuming a V_o in carding equal to 6%, we would then expect a V_m in breaker drawing of $V_o/\sqrt{6} = 2.4\%$. From experience, about .3% should be added to this to find V_{oe} of breaker drawing. Similarly, for finisher drawing, we have a V_{me} of $(2.4 + .3)/\sqrt{6}$ or 1.1 and $V_{oe} = 1.4$.

Thus, significant deviations of actual V's from expected V's have provided sound basis for investigating their causes in the process. With experience, there is usually no difficulty in predicting from the data themselves, to what categories the "looking for trouble" should be confined. Generally, this will be one of the following:

1. Non-uniform drafts. Check tension and draft gears.
2. Mixed stock.
3. Improper roll settings.
4. Non-random sampling or unreliable testing.

PRACTICAL APPLICATION

In practical mill operation of a quality control program, all available short cuts should be employed to bring these methods within the realm of practicability as regards simplification and time savings. For example, the analysis of variance problem can be reduced to a simple average range method, as shown in Figure 3. Furthermore, many of the statistical applications arise only at the time of setting up the control program, such as the determining of desirable testing schedules for checking degree of opening and feeding percentage of raw stock, roll and cylinder speeds, traversing motions, machine settings, yarn tensions, and size variations.

Warnaton - P.O.M. Co., N.Y.C. — Form LC-13a

FINISHER DRG. COEFFICIENT of VARIATION

1. Mill —			2. Dept. DRAWING						3. Equipment Type, Make & Year FINISHER DRG.		
4. Item Tested SLIVER Grs / YARD			5. Mix Cot. 100, 38, S.M.								
6. Sample Length 5 yds.			7. No. of Doublings 6						8. Std. .83	9. High	10. Low	8a. Avg.
	11. Mach. No.	12. Date Jan.	13. Sample Number 1	2	3	4	5	6			14. Range Within	15. Range Overall
a												TOTAL
b	1	3	56.1	56.5	53.5	55.9					3.0	
c	4	3	55.6	57.6	57.1	56.2					2.0	
d	3	3	56.9	58.3	57.2	56.0					2.3	
e	2	3	54.6	56.6	55.8	54.3					2.8	
f												
R_1	Range Overall		2.3	1.8	3.7	1.9						9.7
a												TOTAL
b	5	10	56.0	54.4	55.4	56.1					1.7	
c	6	10	56.6	55.9	57.3	57.3					1.4	
d	1	10	55.2	56.5	55.2	56.5					1.3	
e	2	10	57.8	58.1	58.5	57.0					1.5	
f												
R_2	Range Overall		2.6	3.7	3.2	1.2						10.7
a												TOTAL
b	3	17	54.7	54.0	54.5	54.0					0.7	
c	4	17	55.3	56.0	54.4	54.6					1.6	
d	5	17	54.5	56.0	54.9	54.2					1.8	
e	1	17	53.7	53.7	53.8	54.8					1.0	
f												
R_3	Range Overall		1.6	2.3	1.1	0.8						5.8
R	Total Ranges →										20.6	26.2
$\bar{R}$	Average Range = R ÷ 12 or R ÷ 18										1.72	2.18
σ	STANDARD Deviation: If sample size is 4, multiply $\bar{R}$ by .5; If sample size is 6, multiply $\bar{R}$ by .4										.86	1.04
V	Coefficient of Variation, Divide σ by $\bar{S}$ or $\bar{Sa}$										1.54 %	1.95 %
Exp. V_w	Expected V_{within} = (V_o of previous process) ÷ $\sqrt{(12)}$										1.1 %	—

Copyright 1950 by Warner Textile Consultants, New York 17

FIGURE 3

BIBLIOGRAPHY ON STATISTICAL QUALITY CONTROL AS RELATED TO THE TEXTILE INDUSTRY

The following bibliography was compiled by the Bibliography Committee of the Processing Subcommittee, Textile Technical Committee, of the American Society for Quality Control. The articles listed pertain mainly to the application of statistical methods to textile quality control problems. Some articles were listed which are not devoted to the application of statistical methods. In the opinion of the committee some of these articles contained material which would be of value to the textile quality control engineer. No effort was made to list articles covering materials such as testing and testing instruments. It was the opinion of the Committee that such material would only serve to lengthen the list and thus render it practically useless. Articles devoted to the discussion of statistical control in general terms and its application to other industries were also omitted. This type of material was omitted due to the fact that it is covered very thoroughly in *A Bibliography of Statistical Quality Control* and *Supplement* by Butterbaugh. Books pertaining to statistical quality control in general were listed so that anyone interested can locate the name and publisher of the books which are available.

D. S. Hamby, Chairman
N. C. State College
Raleigh, N. C.

W. S. Smith
West Point Manufacturing Co.
West Point, Ga.

(Miss) Katharine McDiarmid, Librarian
School of Textiles
N. C. State College, Raleigh, N. C.

G. Dent Mangum
National Cotton Council
Washington, D. C.

(Miss) Mary E. Emerson, Librarian
Institute of Textile Technology
Charlottesville, Va.

BIBLIOGRAPHY ON STATISTICAL QUALITY CONTROL AS RELATED TO THE TEXTILE INDUSTRY

1926

ARTICLES

Shewhart, W. A.	Quality control charts	*Bell System Tech. Jour. 5: 593–603. Oct. 1926.*

1930

ARTICLES

Foster, G. A. R.	The grating periodograph for the analysis of series of observations for hidden periodicities	*Textile Inst. Jour. 21: T18–T28. 1930.*
Tippett, L. H. C.	Statistical methods in textile research. Pt. 1: The analysis of complex variations	*Textile Inst. Jour. 21: T105–T126. 1930.*

BOOKS

Ezekiel, Mordecai	Methods of correlation analysis	*New York, Wiley, 1930*

1931

BOOKS

Shewhart, W. A.	Economic control of quality of manufactured product	*New York, Van Nostrand, 1931. 501 p.*

1932

ARTICLES

Skinker, M. K.	Application of control analysis to the quality of varnished cambric tape	*A.S.T.M. Proc. 32(2): 670–675. 1932*

1935

ARTICLES

Pearson, E. S.	The use of range in place of standard deviation in small samples	*Royal Statistical Jour. Suppl. 2 No. 1: 83–98 1935.*
Tippett, L. H. C.	Statistical methods in textile research. Pt. 2: Uses of the binomial and Poisson distributions.	*Textile Inst. Jour. 26: T13–T50. Jan. 1935.*
	Pt. 3: A snap reading method of making time studies of machines and operatives in factory surveys	*Textile Inst. Jour. 26: T51–T70. Feb. 1935*

BOOKS

Pearson, E. S.	Application of statistical methods to industrial standardization and quality control	*British Standards Institution. London. No. 600. 1935. 161 p.*

1936

ARTICLES

Harvey, D.	Statistical methods as an aid to control the quality of materials	*Rayon Textile Monthly 17: 749–750. Nov. 1936.*

1938

ARTICLES

Wiley, N. C.	Statistical methods as an aid in revising specifications	*A.S.T.M. Proc. 38 (2): 647–657. 1938*

1939

ARTICLES

Eustis, W.	Why the Kendall Company is interested in statistical methods	*Industrial Statistics Conf. Proc. 1938: 137–145. 1939.*
Freeman, H. A.	Types of statistical methods used and problems handled in industrial quality control	*Industrial Statistics Conf. Proc. 1938: 2–25. 1939.*
Tippett, L. H. C.	Statistical aspects of the control of quality in textile manufacture	*Industrial Statistics Conf. Proc. 1938: 210–270. 1939.*
Tippett, L. H. C.	Statistical principles of experimentation with particular reference to experimentation in textile factories	*Industrial Statistics Conf. Proc. 1938: 174–209. 1939.*
Wadsworth, G. P.	Some statistical techniques underlying the field of quality control	*Industrial Statistics Conf. Proc. 1938: 26–46. 1939.*

BOOKS

Arkin, Herbert	Statistical methods as applied to economics, business, education..	*New York, Barnes and Noble, 1939. 224 p.*
Industrial Statistics Conference, Mass. Ins. of Technology	Proceedings 1938	*New York, Pitman, 1939, 315 p.*

1940

ARTICLES

Walker, A. C.	Scientific approach to textile problems	*Amer. Dyestuff Rptr. 29: 217–220. April 29, 1940.*

BOOKS

American Society for Testing Materials	A.S.T.M. manual on presentation of data	*Philadelphia, 1940. 73 p.*

1941

ARTICLES

Ashcroft, A. G.	An outline of organization for quality control	*Taylor Society Bull. 16: 81–82. Apr. 1941*
Gaillard, John	Quality control: an improved method; guide for quality control and control chart method of analyzing data	*Industrial Standardization. 12: 137–141. June 1941.*
Martindale, J. G.	A correlation periodograph for the measurement of periods in disturbed wave-forms	*Textile Inst. Jour. 32: T71–T82. May 1941.*
Schwarz, E. R. & Fox, K. R.	Application of rank correlation to the development of testing methods	*Textile Res. Jour. 11: 482–489. Oct. 1941.*

BOOKS

American Standards Assn.	Guide for quality control and control chart method of analyzing data Z1.1; Z1.2	*New York, May 1941. 66 p.*
Simon, L. E.	An engineer's manual of statistical methods	*New York, Wiley, 1941. 231 p.*

1942

ARTICLES

Keeling, D. B. & Cisne, L. E.	Using double sampling inspection in a manufacturing plant	*Bell System Tech. Jour. 21: 37–50. June 1942.*

BOOKS

American Standards Assn.	Control chart method of controlling quality during production – Z1.3	*New York, April 1942. 41 p.*

1943

ARTICLES

Anon.	Statistical quality control in textiles needed	*Rayon Textile Monthly. 24: 88. Nov. 1943.*
Ashcroft, A. G.	Quality control charts aid textile manufacturers in meeting strict requirements of Army and Navy	*Textile World. 93: 69–71. Dec. 1943.*
Philip, R. W.	Laboratory at Tallassee is "nerve center" of mill	*Cotton. 107: 79–83. Feb. 1943.*
Wilsdon, B. H.	Postwar industry and quality control	*Soc. Dyers and Colourists Jour. 59: 161–164. Aug. 1943.*
Wilsdon, B. H.	Quality control in postwar trade	*Textile Manufacturer. 69: 520–521. Dec. 1943.*

1944

ARTICLES

Anon.	Sampling plan developed by Quartermaster for woolen textiles	*Textile World, 94: 88–89. May 1944.*
Ashcroft, A. G.	The interpretation of laboratory tests as quality indices in textiles	*Amer. Dyestuff Rptr. 33: 486–491. Nov. 20, 1944. Also in A.S.T.M. Bull. 131: 27–31. Dec. 1944.*
Beckwith, O. P.	A fresh approach to quality control	*Textile World. 94: 79–81, 134, 136, 138, 140. Jan. 1944.*
Beckwith, O. P.	The quality control chart technique in applied textile research	*Textile Research. 14: 319–325. Oct. 1944.*
Steadman, P. M.	Quality control posts mill production odds	*Textile World. 94: 63. July 1944.*

BOOKS

Fisher, R. A.	Statistical methods for research workers	*London, Oliver & Boyd, 1944. 350 p.*

1945

ARTICLES

Ashcroft, A. G.	How should laboratory test be used in postwar textile programs	*Industrial Standardization. 16: 41–44. Feb. 1945.*
Bryans, H. B.	Standardization is control device of modern industry	*Textile Colorist. 67: 570–571, 589. Jan. 1945.*
Carnegie Inst. Technology	Bibliography on Statistical Quality Control	*Quality Control Reports No. 11. Sept. 1945. 49 p.*
Dennis, A. E.	Quality control by statistical methods	*Rayon Textile Monthly. 26: 397–399. Aug. 1945.*
Kuvin, L.	How statistics will help in postwar textile problems	*Industrial Standardization. 16: 103–104. May 1945.*
Larose, P.	Application of statistics to textile manufacture	*Canad. Textile Jour. 62: 39, 42, 44. Jan. 12, 1945.*
Miedendorp, H., Jr.	Quality control with control instruments	*Rayon Textile Monthly 26: 547–549. Oct. 1945.*

BOOKS

U.S. Army Service Forces. Office of Quartermaster Gen.	Inspection handbook on sampling for quality control	*Washington, Dec. 1945. 186 p.*

1946

ARTICLES

Anon.	Statistical textile research	*Ambassador. No. 3: 116. 1946.*
Ashcroft, A. G.	Textile statistical control a permanent feature	*Industrial Quality Control. 2(4a): 15–16. Jan. 1946*
Lyons, W. J.	An approximate function for testing the significance of difference according to the "student" – Fisher t–test.	*Textile Research Jour. 16: 438–440. Sept. 1946.*

BOOKS

Butterbaugh, G. I.	A bibliography of statistical quality control	*Seattle, Univ. Washington Press, 1946. 114 p.*
Edelman, W. B.	Determination of statistical control and related factors in the performance of breaking strength testing of fabrics	*Office of Quartermaster General, Military Planning Div., Research & Development Branch. Textile Series Rept. No. 26. 1946. 10 p.*
Grant, E. L.	Statistical quality control	*New York, McGraw–Hill, 1946. 563 p.*

1947

ARTICLES

Anon.	Cotton quality control	*Amer. Wool & Cotton Reptr. 61: 9–10, 42. Oct. 23, 1947*
Anon.	Quality control discussed by Gaston County Southern Textile Assn.	*Textile Industries. 111: 117. Nov. 1947*
Anon.	Quality control testing	*Amer. Wool & Cotton Reptr. 61: 27, 29, 31, 33. Oct. 16, 1947.*
Stone, W. J.	Suggestions for quality control in spinning finer cotton yarns	*Textile Age. 11: 52–54, 56, 58. Oct. 1947.*
Tippett, L. H. C.	Quality control in the textile industry	*Textile Inst. Jour. 38: P594–P600. Dec: 1947.*

BOOKS

American Society for Quality Control	Conference papers; First annual convention of American Society for Quality Control and Second Midwest Quality Control Conference	*Chicago, 1947. 281 p.*
Peach, Paul	An introduction to industrial statistics and quality control	*Raleigh, N.C., Edwards & Broughton Co., 1947. 235 p.*

Rice, W. B.	Control charts in factory management	*New York, Wiley, 1947. 149 p.*

1948

ARTICLES

Anthony, A. D. & Souther, R. H.	Quality control charts aid carding and spinning	*Textile World. 98: 111, 113. Mar. 1948.*
Ashner, R. M.	Control laboratory can save money for a mill	*Textile World. 98: 117–119. July 1948.*
Backer, S.	The use of acceptance testing data to substantiate specification requirements	*Amer. Dyestuff Rptr. 37: 603–612. Sept. 20, 1948.*
Bitzenhofer, O.	Advantage of statistical data on weaving performance and quality	*Rayon Textile Monthly. 29: 61–62, 65–66, 52–54, Jan., Feb., April. 1948.*
Caldwell, S. A. G.	Plant modernization and quality control in linen manufacture	*Textile Manufacturer. 74: 410–411. Sept. 1948.*
Dunod, Jean	Incidences sur le rendement du controle de la qualite dans l'industrie textile	*L'Industrie Textile. 65: 3–8. Jan. 1948. In French.*
Frederick, J.K., Jr.	Statistics and textiles	*Lowell Textile Inst. Bull. Series 51, No. 3. Feb. 1948. 15 p.*
Hamby, D. S.	Statistical quality control	*Textile Industries. 112: 85–87. Jan. 1948.*
Hard, E.	System for maintaining quality control	*Textile Industries. 112: 105–107. Feb. 1948.*
Holmes, M. N.	Quality control in a hosiery mill	*Hosiery & Underwear Rev. 31: 163–167, 187–188. May 1948.*
Martindale, J. C.	Application of statistical methods to the scientific study of spinning and weaving	*L'Ingenieur Textile. 370: 113–134. 1948*
Sarker, B. & Ramachandran, T.N.	Statistical methods of quality control in textile industry	*Indian Textile Jour. 58: 723–724. May 1948.*
Starling, W. H.	Quality control in hosiery manufacture	*Canadian Textile Seminar, 1st, 1948. 4 p.*
Wignall, H.	Quality control in half hose manufacture	*Textile Manufacturer. 74: 316–318. July 1948.*

BOOKS

Enrick, N. L.	Quality control	*New York, Industrial Press, 1948. 122 p.*

Freeman, H. A.	Statistical technique in industrial research and quality control	*New York, Wiley, 1948. 178 p.*
Herdan, G.	Quality control by statistical methods	*London, T. Nelson & Sons, Ltd., 1948. 251 p.*
Kennedy, C. W.	Quality control methods	*New York, Prentice–Hall 1948. 243 p.*
Rice, William B.	Control charts in factory management	*New York, Wiley, 1948. 149 p.*
Rutherford, J. G.	Quality control in industry	*New York, Pitman, 1948. 201 p.*

1949

ARTICLES

Anon.	Quality and waste control	*Amer. Wool & Cotton Reptr. 63: 9–10, June 30, 1949; 10–11, 33. July 7, 1949; 9–10. July 21, 1949.*
Anon.	Quality control as a money saver	*Lingerie Merchandising. 5: 93–96. May 1949.*
Anon.	Statistical quality control	*Fortune. 40: 161–164. Dec. 1949.*
Findley, E. M., Jr.	Regaining quality requires definite plan	*Textile World. 99: 103–105. May 1949.*
Hill, D. W.	The cotton industry in a changing world. Production problems in quality.	*Textile Manufacturer. 75: 521–522. Nov. 1949.*
McFarlane, R. A. & Wilcock, C. C.	Control of quality in a rayon piece dyeing and finishing works	*Textile Inst. Jour. 40: P583–P607. July 1949.*
Sears, W. B.	Quality control in the rayon plant	*Rayon & Synthetic Textiles. 30: 57–60. Oct. 1949.*

1950

ARTICLES

Anon.	The control of quality	*Fibres. 11: 196–198. June 1950*
Anon.	Mill performance charts. "We wouldn't be without them"	*Textile Industries. 114: 100–105. Oct. 1950.*
Anon.	Key points necessary for quality control in textile mills	*Textile Industries. 114: 96. Dec. 1950.*

Anon.	Production efficiency and textile quality	*Textile Recorder. 67: 92–93. May 1950.*
Anon.	Quality and cost control through instrumentation	*Rayon and Synthetic Textiles. 31: 91–93. Feb. 1950.*
Anon.	Quality control at Hardwick Woolen Mills	*Textile Industries. 114: 115–116. Oct. 1950.*
Anon.	Quality control in a hosiery mill	*Hosiery and Underwear Rev. 33: 131, 151. Sept. 1950.*
Anon.	Quality control in a lingerie plant	*Lingerie Merchandising. 6: 92–94. July 1950.*
Anon.	Quality control in cotton manufacturing	*Amer. Wool & Cotton Reptr. 64: 14–15. Apr. 6, 1950.*
Anon.	Quality control in Whitin textile machinery manufacture	*Whitin Review., 17: 3–12. July, Aug. 1950.*
Anon.	Quality control of carding and spinning through methods and systems of inspection	*Textile Bull. 76: 43–44, 46, 48, 50. Mar. 1950.*
Anon.	Quality control of slashing and weaving through methods and systems of inspection	*Textile Bull. 76: 59–60, 62. Mar. 1950.*
Anon.	Statistical quality control	*Factory Management & Maintenance. 108: 136–138. Jan. 1950.*
Byrd, F. L.	A practical quality control system	*Textile Industries. 114: 95–98. June 1950.*
De La Rama, Jess	Incoming material inspection pays off at Alexander Smith	*Textile World. 100: 71, 330–333, 339–340. May 1950*
Enrick, N. L.	Sequential sampling for better quality control	*Amer. Wool & Cotton Reptr. 64: 17, 18. Aug. 24, 1950.*
Everhart, F. D.	Control lab improves quality at Pilot Mills	*Textile Forum 7: 19–20. June 1950.*
Hamby, D. S.	Measure up your quality control lab	*Textile World. 100: 120–121, 123. Sept. 1950.*
Hand, T. R.	Quality control indicator cuts production costs	*Instruments. 23: 336. Apr. 1950.*
Helliwell, E. H.	Chalk marks reduce imperfect work	*Textile World. 100: 113, 180, 182, 184. Jan. 1950*

Mehta, A. M.	Quality control in bleach house	*Indian Textile Jour. 60: 740–741. June 1950.*
Newson, A. C. L.	Quality control in mercerized yarns	*Hosiery & Underwear Rev. 33: 101–102, 109. July 1950.*
Osborne, James	The case history of the sickness and recovery of a textile mill.	
	Pt. 1: The diagnosis and cure of the many difficulties found in the opening and picking departments	*Textile Age. 14: 54–57. May 1950.*
	Pt. 2: Waste inspection provides clue to program for rehabilitation in the card room of this sheeting mill	*Textile Age. 14: 40–43. June 1950.*
	Pt. 3: A thorough overhall of the drawing frames along with the tightening up of the operating discipline and supervision produced good results	*Textile Age. 14: 64–66. Aug. 1950*
	Pt. 4: A planned system for the roving department. Reduce the number of thick places in the roving speeds up production and cuts the amount of waste	*Textile Age. 14: 69–73. Oct. 1950.*
	Pt. 5: Improvement in the spinning room produced better quality yarns for weaving and knitting	*Textile Age. 14: 67–73. Dec. 1950.*
Pomfret, N. H.	Productivity in cotton spinning	*Textile Weekly. 46: 176, 178, 180. July 21, 1950.*
Rudnick, E. S.	Statistical quality control at work in the cotton mill	*Textile Research Jour. 20: 727–734. Oct. 1950.*
Shackleton, W. T.	Quality in yarns and cloth	*Textile Weekly. 45: 1044, 1046, 1048, 1050, 1052, 1054 1056, 1058. Apr. 28, 1950.*
Shackleton, W. T.	Weaving properties of yarn	*Textile Weekly. 46: 1037–1038, 1040. Oct. 20, 1950; 46: 1124–1126. Oct. 27, 1950.*
Smith, G. A.	Textile testing – key to better fabrics	*Laundry & Dry Cleaning Jour. of Canada. 3: 26–27, 51. July 1950.*
Vickers, Albert	Quality Control in Worsted Spinning	*Bradford Textile Soc. Jour. 1949/50: 59–63. 1950.*
Wassman, G.	Just one form, but it works three ways; loom control report	*Factory Management & Maintenance. 108: 124. July 1950.*

BOOKS

American Society for Testing Materials	Symposium on application of statistics	*Philadelphia, 1950. 36 p.*

Arkin Herbert	Tables for statisticians	*New York, Barnes & Noble, 1950. 152 p.*
Cochran, W. G.	Experimental designs	*New York, Wiley, 1950. 454 p.*
LeDuc, Harold	Statistical quality control in the yarn mill. A common sense approach to the control of yarn numbers	*New York University, American Society for Quality Control, 1950. 20 p.*
Schrock, E. M.	Quality control and statistical methods	*New York, Reinhold, 1950. 213 p.*
Tippett, L. H. C.	Technological applications of statistics	*New York, Wiley, 1950. 189 p.*
U.S. Testing Co. Inc.	Cotton quality through cotton fiber testing	*Memphis, Tenn., 1950. 16 p.*

1951

ARTICLES

Anon.	Claims wool goods future hinges upon quality control	*Amer. Wool & Cotton Reptr. 65: 13–14, 56–57. Sept. 13, 1951.*
Anon.	Control of yarn quality	*Textile Mercury & Argus. 125: 204–207. Aug. 3, 1951.*
Anon.	Cotton picker inspection big aid in quality control	*Amer. Wool & Cotton Reptr. 65: 19, 21, 115, 118. May 10, 1951.*
Anon.	Fiber control featured at quality control meeting	*Textile World. 101: 133, 135, 184, 186, 189, July 1951.*
Anon.	Fifty–six causes of tangled yarn and how to remedy them	*Textile World. 101: 127. May 1951.*
Anon.	Forty–nine cloth defects and what may cause them	*Textile World. 101: 113–118. Aug. 1951.*
Anon.	How to reduce yarn defects	*Textile Industries. 115: 105–107. June 1951.*
Anon.	Instruments for quality control	*Textile Recorder. 69: 109. June 1951.*
Anon.	Laboratory testing perfects warp knitting	*Amer. Wool & Cotton Reptr. 65: 9–10. March 29, 1951.*
Anon.	Outerwear organization initiates quality control project	*Apparel Manufacturer. 28: 47–49. Dec. 1951.*
Anon.	Quality control in textiles	*Textile Weekly. 47: 1280, 1282. May 1951.*

Anon.	Quality control in yarns	*Textile Weekly. 48: 294, 300–301. Aug. 3, 1951.*
Anon.	Textile research makes a notable four year advance	*Amer. Wool & Cotton Reptr. 65: 13–35. Jan. 25, 1951.*
Ashner, R. M.	Quality control of cotton fibers	*Textile Industries. 115: 143, 145, 147, 149, 151. Aug. 1951.*
Bard, M. A.	Controlling quality in a small mill	*Hosiery & Underwear Review. 34: 138–139, 156. July 1951.*
Clegg, O.	Quality control and the new fibers	*Textile Mercury & Argus. 124: 141, 143–44. Jan. 26, 1951; 124: 185–188. Feb. 2, 1951; 124: 231–232, 252, Feb. 9, 1951*
Coplan, M. J.	Application of statistical quality control to cotton mills	*Inst. Text. Tech. Report No. 2 May 15, 1951. 30 p.*
Enrick, N. L.	Recent progress in statistical quality control in the textile industry	*Textile Age. 15: 48–51. Sept. 1951.*
Feng, Ivan and Hamby, D. S.	Quality control and nep control papers heard by S.T.A. Division	*Textile Bull. 77: 58, 60, 62, 65. Jan. 1951.*
Harris, Tom S.	Nep count reduced by opening and picking changes	*Textile Industries 115: 98–100. Aug. 1951.*
Horner, L. I.	Quality control in warping continuous filament acetate rayon from bobbins	*Textile Age. 15: 50–52. Oct. 1951.*
Karl, W. A.	What top management expects from statistical quality control	*Textile Bull. 77: 63–64, 66. Nov. 1951.*
Kershaw, S.	Quality and production in worsted spinning	*Textile Inst. Jour. 42: P877–P884. Sept. 1951.*
LeDuc, H. A.	Statistical quality control in the yarn mill	*Textile Bull. 77: 51–54. Feb. 1951.*
Morris, P. F.	Rocky Mount's experience with control boards	*Textile Industries. 115: 121, 123, 125, 127. Aug. 1951.*
Noechel, F. W.	Application of quality control in woolen & worsted manufacturing	*Textile Age. 15: 80–82: Dec. 1951.*
Noechel, F. W.	Quality control in wool textile mills	*Canadian Textile Jour. 78: 67, 69–70. Dec. 21, 1951.*
Olsen, Earl	Picker lap tests an effective quality control device	*Textile Industries. 115: 105, 106. Jan. 1951.*

Osborne, James	A case history of the sickness and recovery of a textile mill. Pt. 6: Correcting faults in the spooling warping, and slashing departments led to better prepared goods for the weave room	*Textile Age. 15: 62–65. Mar. 1951.*
Stuart, W. L.	Technical factors in economics of textile production	*Textile Jour. Australia. 26: 698–700. Sept. 20, 1951.*
Thomason, W. A., Jr.	How about quality control for small mills?	*Textile World. 101: 99–101. Jan. 1951.*
Thomason, W. A., Jr.	Teamwork gives quality weaving at Burlington Mills Plant	*Textile World. 101: 122–133. Feb. 1951.*
Wiggers, B. G.	Statistical quality control in the textile industry	*Enka and Breda Rayon Revue. 5: 13–28 Feb. 1951. (In Dutch)*

BOOKS

American Society for Testing Materials	A.S.T.M. manual on quality control of materials	*Philadelphia, 1951. 127 p.*
Butterbaugh, G. I.	A bibliography of statistical quality control – supplement	*Seattle, Univ. Washington Press, 1951. 141 p.*
Cotton Research Committee of Texas	Quality control in the cotton industry	*Austin, Texas, 1951. 44 p.*
Feigenbaum, A. V.	Quality control; principles, practice, and administration	*New York, McGraw–Hill Book Co., 1951. 443 p.*
Heide, J. D.	Industrial process control by statistical methods	*New York, McGraw–Hill Book Co., 1951. 279 p.*
Juran, J. M.	Quality control handbook	*New York, McGraw–Hill Book Co., 1951. 800 p.*

1952

ARTICLES

Anon.	Control charts as an aid to quality	*Textile Industries. 116: 112. Feb. 1952.*
Anon.	Knit goods stabilizing machines simplifying quality control	*Textile Industries. 116: 169–170. Feb. 1952.*
Anon.	Quality control urged as important cotton production tool	*America's Textile Reptr. 66: 59, 61, 95. May 15, 1952.*
Anon.	Significance of quality control	*Textile Age. 16: 74–76. June 1952.*

Dvivedi, S. S.	Quality control and control charts	*Indian Textile Jour. 62: 233–236. Jan. 1952.*
McDonald, J. W., Jr.	Use of statistics in the control of quality	*Institute News, Underwear Institute. 19: 16, 18, 22. Mar. 1952.*
Packer, Edward	Control testing in textiles	*Textile Mercury & Argus. 126: 420, 423, 425–426. Mar. 7, 1952; 126: 471–472, 475. Mar. 14, 1952.*
Parks, Remon	Quality control. Article 7 of the "Supervisor and his responsibilities"	*Textile Industries 116: 138–139. Jan. 1952.*
Prentice, W.	Process controls in wool textile mills	*Canadian Textile Jour. 69: 59–60. Feb. 1, 1952.*
Rab, Joseph	Quality control methods adaptable to knitted outerwear mills	*Knitted Outerwear Times. 20: 6–7, 14–15. Mar. 24, 1952.*
Souther, R. H.	Tar spots and quality control	*Textile Forum 9: 63–64, 78. June 1952.*
Webster, A.	Quality control in textile production	*Textile Manufacturer 78: 191–193, 208. Apr. 1952.*

BOOKS

Amer. Society for Quality Control	Quality Control Conference Papers 1952, Sixth Annual Convention	*New York, The Society, 1952. 452 p.*